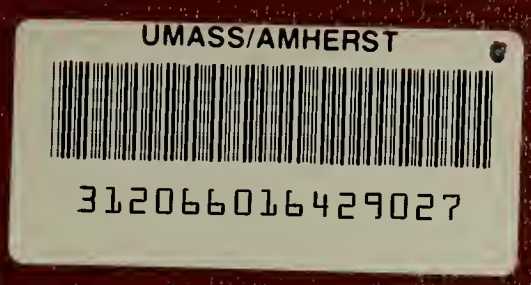

MASSACHUSETTS COASTAL COMMERCIAL LOBSTER TRAP SAMPLING PROGRAM MAY-NOVEMBER, 1992

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ABSTRACT

This is the Massachusetts Division of Marine Fisheries twelfth annual assessment of the status of the American lobster resource in Massachusetts coastal waters. During the period of May through November, 1992, eighty-seven sampling trips were made aboard commercial lobster vessels. A total of 41,840 lobster was sampled from 17,984 trap hauls. The catch rate of marketable lobster, 0.716 lobster per trap, was only 9.9% lower than the 1991 index, 0.795. The proportion of females ovigerous, 11.9%, was higher than in the previous year (9.8%). The coast-wide fishing mortality estimate was similar to the record high reached in 1991. Exploitation rate, 0.69, mean carapace length of marketable lobster, 88.8 mm, coast-wide mean size of egg-bearing females, 85.5 mm, and the percentage of culls, 18.5%, were similar to 1991 indices. As observed in previous years, less than 1% of the lobster sampled from traps were dead.

An assessment of the sea sampling design was accomplished in order to determine optimal use of available man-power and whether acceptable precision could be achieved at lower levels of sampling effort. Based on the relationships of confidence intervals to trap hauls per trip, a minimum of 100 traps per trip was determined acceptable. A quarterly data collection scheme was found unacceptable due to seasonal variation in variables and the lack of homogeneity in existing monthly data within quarters. All proposed strategies for reduction of sampling effort within a monthly sampling design had significant effects on population estimates and the time series.

INTRODUCTION

This is the Massachusetts Division of Marine Fisheries (DMF) twelfth annual assessment of the status of the American lobster resource in Massachusetts coastal waters. Since the lobster resource supports the most economically important single-species fishery in Massachusetts coastal waters, a long-term coastwide lobster monitoring program yielding biological and catch per unit effort data was devised and initiated in Massachusetts in May, 1981. A sea sampling/survey design was chosen by which both catch per unit effort and biological data could be collected temporally and areally with sufficient precision for stock assessments. The objective was to assess variations in population parameters due to environmental factors, fishing pressure, and regulatory changes.

Data collected during the 1992 coastwide commercial lobster trap sampling program are summarized below. Parameter trends occurring during the 1981-1992 study period are presented.

STUDY AREA

The study area is primarily defined by the Massachusetts territorial sea, except where lobstering activities of cooperating commercial lobstermen exceeded territorial boundaries (Figure 1). Territorial waters total 5,322 sq km (2,055 sq n mi), of which an estimated 60% is considered major lobster habitat. Six sampling regions, Cape Ann, Beverly-Salem, Boston Harbor, Cape Cod Bay, outer Cape Cod, and Buzzards Bay, were chosen for coverage of the major lobstering regions of the state. For convenience, these regions are depicted in Figure 1 as generalized hatch-marked areas wherein lobster gear sampled may be discontinuously distributed.

SAMPLING PROCEDURE

Sampling of coastal waters was accomplished by monitoring catches during the normal lobstering operations of volunteer commercial lobstermen in each designated region. Multiple lobstering operations were observed to reduce bias from varying degrees of lobstering skill and to enhance areal coverage. Pot-sampling trips were day trips, conducted a minimum of once per month per region during the major lobstering season, May-November.

Utilizing portable cassette tape recorders, sea samplers recorded carapace length (to the nearest mm); sex; and condition, including the degree of shell hardness, culls and other shell damage, external gross pathology, mortality, and presence of extruded ova on females (ovigerous). Catch in number of lobster, number of trap hauls, set-over-days, trap and bait type were also recorded. Trap locations were recorded from LORAN and plotted on nautical charts. Depth information was then acquired from the charts as a coast-wide standard to avoid variability from tidal fluctuations.

ANALYTICAL PROCEDURES

Data were computer coded and keypunched with a microcomputer data entry program. The data base was subsequently transferred for analysis to the National Marine Fisheries Service's Digital Equipment Corporation VAX-11/780 computer system at Wood Hole Oceanographic Institution. A computer auditing process was used to uncover keypunch and recording errors and statistical analyses were performed with SPSS (Nie 1983) statistical sub-programs.

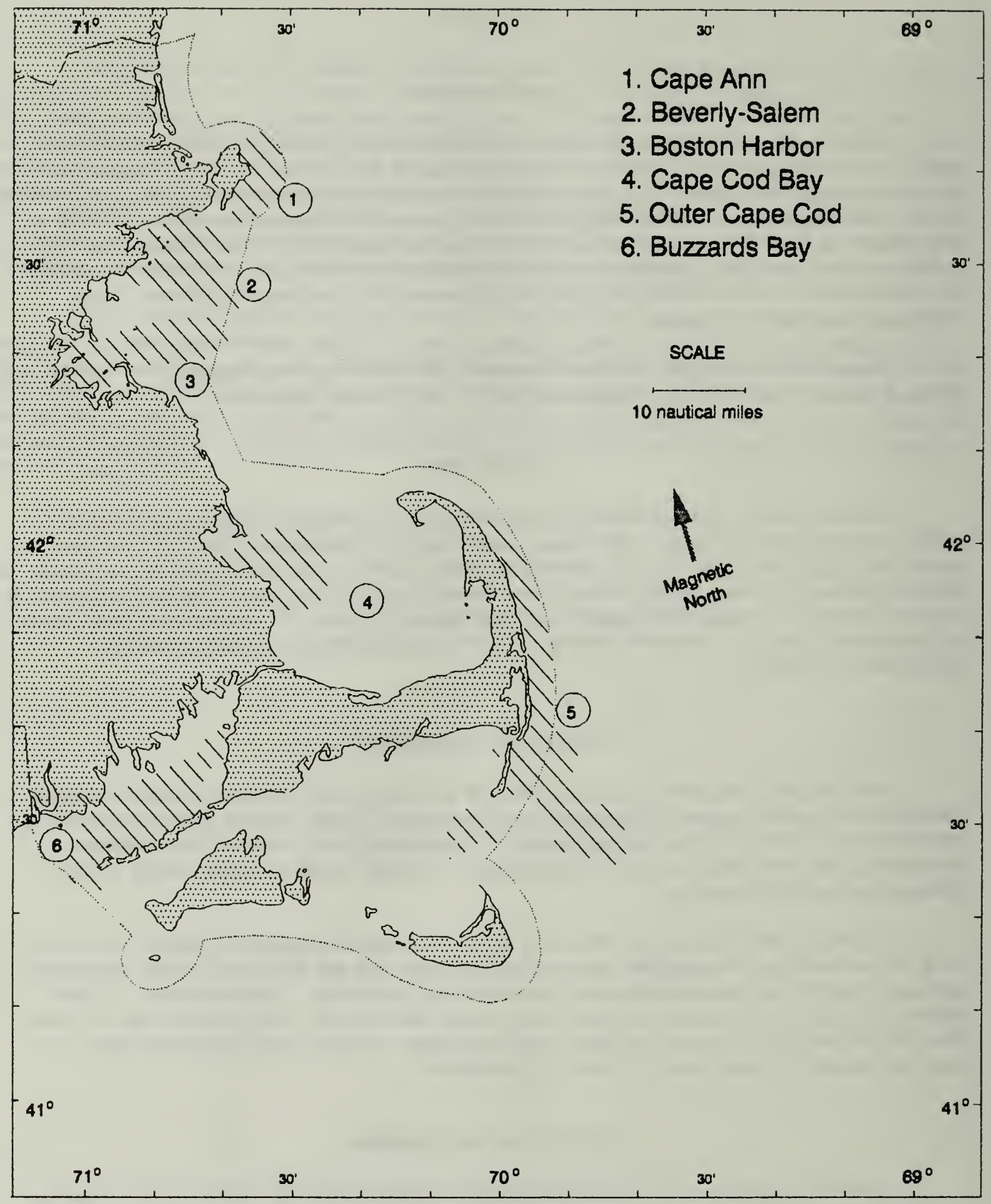


Figure 1. Map of Massachusetts coast with six sampling regions (hatch-marked) and territorial sea boundary (stippled).

Because parameter means exhibit significant regional and monthly variation, an areal and temporal data weighting scheme was incorporated into analytical software. As a result, each month's data contribute equally to regional parameter means which are weighted by area in square nautical miles to generate coastwide means.

Unless specified otherwise, the terms "legal" or "legal sized" lobster include all lobster in the carapace length category $\geq$ 82.6 mm. The marketable segment of this category, which excludes ovigerous females, is analyzed separately and referred to as "marketable lobster". The sublegal length category includes all lobster < 82.6 mm.

The catch rates of marketable lobster are expressed as CTH'_3. This is catch per trap haul standardized to 3 set-over-days (Estrella and McKiernan 1989).

Estimates of total instantaneous mortality (Z) and total annual mortality ($A=1-e^{-Z}$) were computed by two methods which produce extremes in the possible range of estimates. The method of Gulland (1969) requires computation of the regression line slope of natural log transformed numbers at estimated age (15% molt groups, 14% for Buzzards Bay, were derived from tagging data). Beverton and Holt's (1956) process employs von Bertalanffy Growth Equation parameters (from Fair 1977) and mean and minimum length of exploitable sizes.

Estimates of fishing mortality (F) were calculated with cohort analysis (Pope 1972). Rates of exploitation were calculated with the equation $u=FA/Z$, where F= fishing mortality, A= total annual mortality, and Z= total instantaneous mortality.

Lobster landings data were derived from lobstermen's catch reports which are compiled annually by the DMF Commercial Fisheries Statistics Project.

Since current management strategy stresses uniform coastwide regulations, all data are grouped for a coastwide analysis. However, the uniqueness of the Massachusetts coastline, its role as a temperature barrier which profoundly affects many marine species (Colton 1964), and the influence of offshore lobster stocks on the inshore resource mandate a regional data treatment as well.

RESULTS AND DISCUSSION

Commercial Lobster Sampling

During the period of May through November, 1992, ninety-one sampling trips were made aboard commercial lobster vessels in Massachusetts coastal waters. A total of 41,840 lobster was sampled from 17,984 trap hauls.

The 1992 coastwide mean catch per unit effort index (CTH'_3), 0.716 marketable lobster per trap, was 9.9% lower than the 1991 index, 0.795 (Appendix Table 1). Total Massachusetts commercial landings, 14,775,458 lbs, decreased by 7.8% from 1991. Landings from territorial waters, (9,622,211 lbs), decreased by 12.4%. Landings and catch rate trends are depicted in Figure 2. The catch rates of sublegal lobster decreased significantly between 1991 and 1992 (Appendix Tables 2 and 3).

Of all females sampled during 1992, 11.9% were ovigerous compared to 9.8% in 1991 (Appendix Table 4). Trends in abundance of ovigerous females are depicted in Figure 3 (Appendix Tables 4-6).

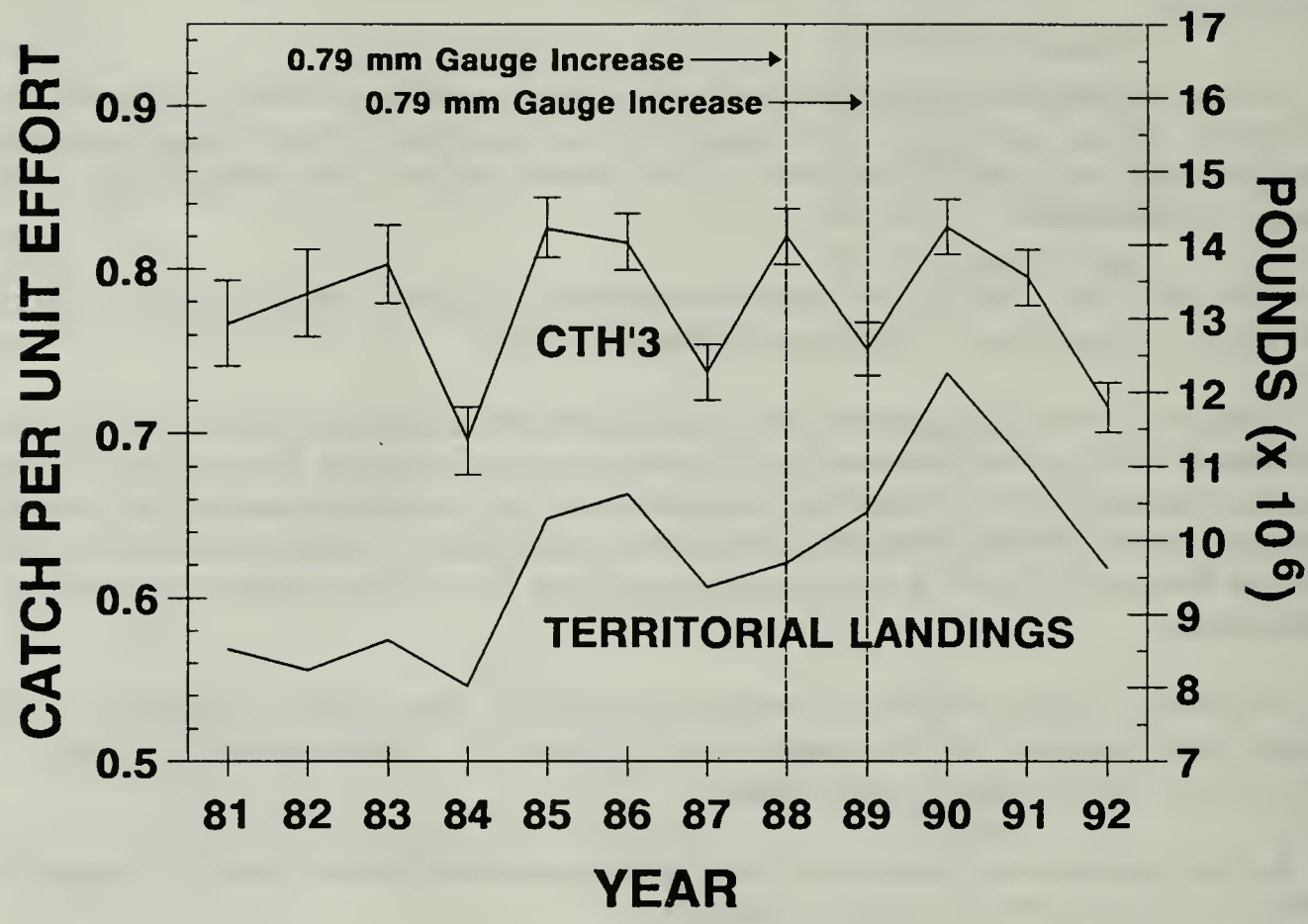


Figure 2. Catch per unit effort of marketable American lobster from commercial trap sampling and Massachusetts lobster landings from territorial waters, 1981-1992.

Approximately 93% of the legal catch in our inshore regions (Cape Ann south through Cape Cod Bay and Buzzards Bay) was comprised of new recruits (83 mm-94 mm CL), i.e., lobster which recruited to the legal size range during their most recent molt (Appendix Table 7). This index of the effect of fishing pressure on the size frequency was 94% in 1991. The index fluctuated from 54% to 57% between the two years for the primarily offshore migrant lobster sampled east of Cape Cod. Estimates of total mortality (Z) differed little from 1991 data. Indices for inshore Gulf of Maine regions (Z = 1.57-3.54, A = 79%-97%) and Buzzards Bay (Z = 2.70-3.81, A = 93%-98%) depict a heavily exploited resource while those for the outer Cape Cod region (Z = 0.72-0.78, A = 51%-54%) indicate that a lower level of fishing pressure was exerted on this lobster group (Appendix Tables 8a and 8b).

Estimates of instantaneous fishing mortality (F), the proportion of all deaths which are attributed to fishing, ranged from 0.61 off outer Cape Cod to 2.26 in Buzzards Bay (Appendix Table 9). Exploitation rates (u), i.e. the fraction of the population that is removed by fishing, were similar to 1991 data (Appendix Table 10).

The relationship between fishing mortality, rate of exploitation, and mean lobster size is depicted in Figure 4. Carapace length exhibited a downward trend as fishing mortality and exploitation rates increased through 1987. Thereafter carapace length increases of 0.79 mm occurred in 1988 (mean size = 88.2 mm) and 1989 (mean size = 88.9 mm, Appendix Table 11) which probably reflected the similar numerical change

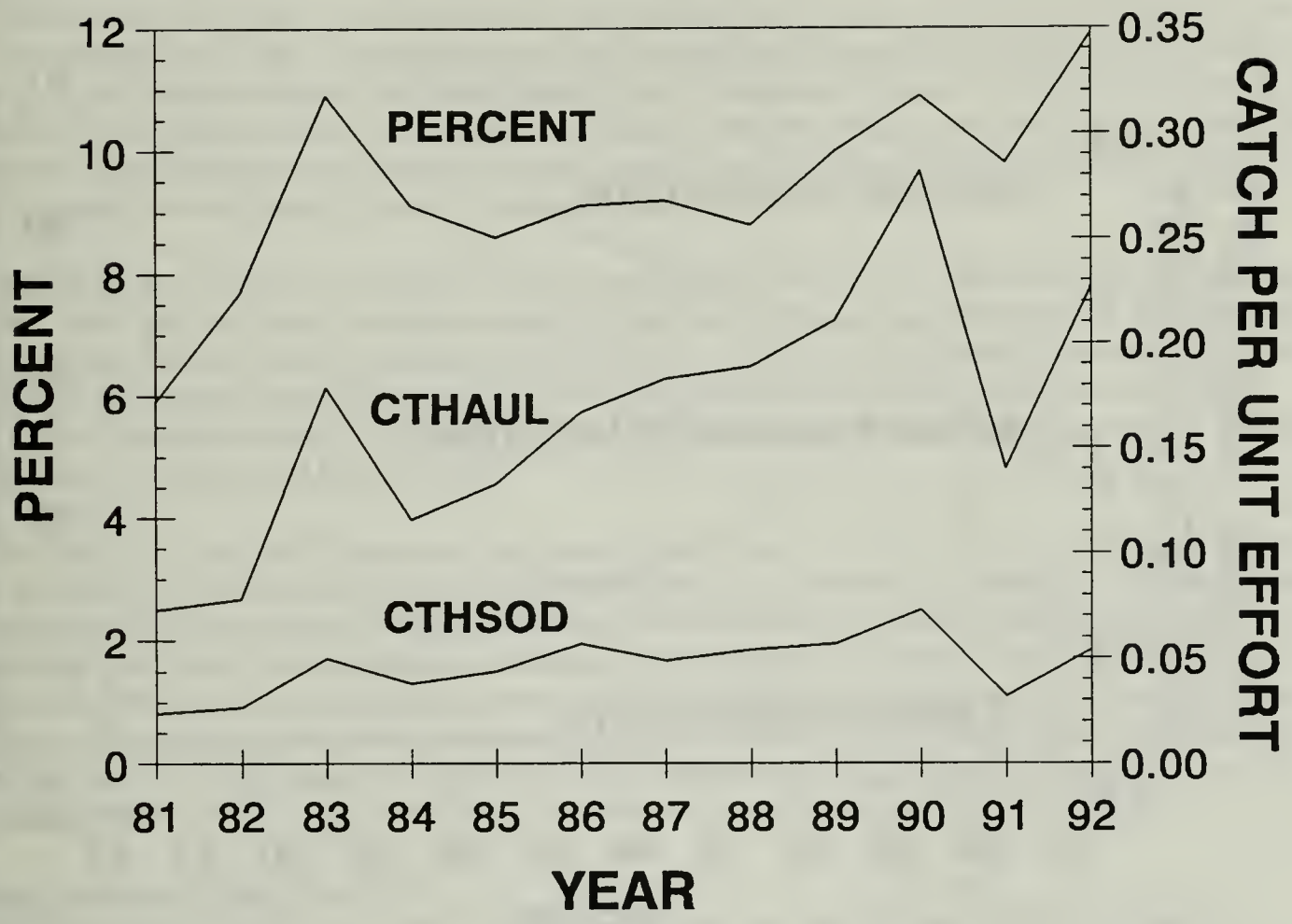


Figure 3. Relative abundance of ovigerous female American lobster in percent of total females and catch per unit effort, Massachusetts coastal waters, 1981-1991.

in the minimum legal size during those years. Fishing mortality and exploitation rates appeared to stabilize accordingly. All three indices increased slightly in 1992.

Sublegal sized lobster averaged 76.2 mm carapace length during 1992 compared to 76.7 mm during 1991 (Appendix Table 12). The mean size of all ovigerous females decreased from 86.0 mm in 1991 to 85.5 mm in 1992.

The percentage of culls (lobster with one or both claws missing or regenerating) among all lobster sampled fluctuated from 18.1% in 1991 to 18.5% in 1992 (Appendix Table 14). The cull rates for legal and marketable size groups increased slightly while that for sublegal size groups was similar to the previous year (Appendix Tables 15-17). The cull rate for Buzzards Bay increased substantially and nearly doubled for legal and marketable size groups.

The coast-wide incidence of lobster found dead in traps was 0.08%. This was lower than that of the previous year (Appendix Table 18). The index for Buzzards Bay, which had been abnormally high in 1991 (consistent with other southern New England areas), returned to a relatively normal level of 0.10%.

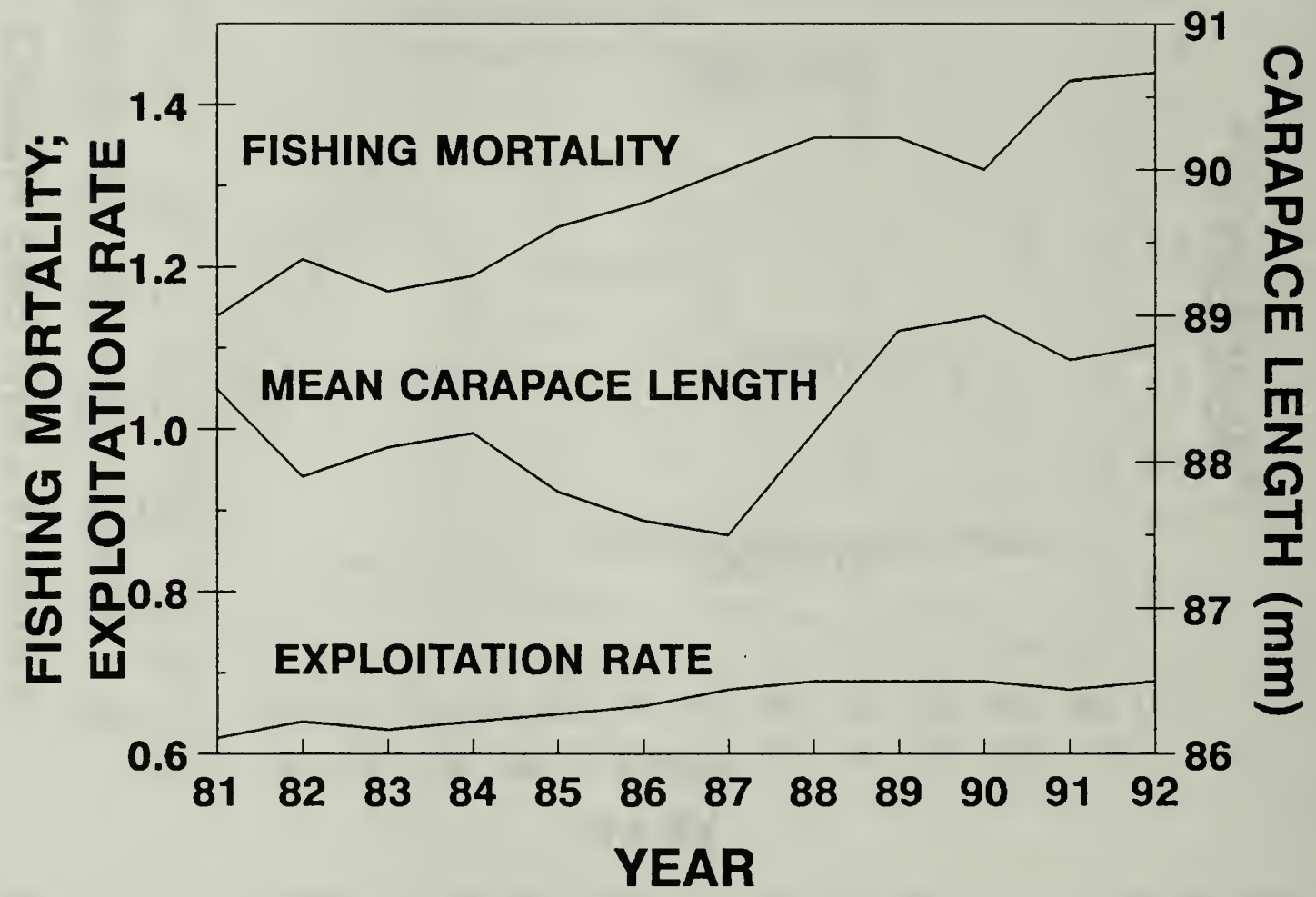


Figure 4. Relationship between exploitation rate, fishing mortality, and mean carapace length of marketable American lobster, Massachusetts coastal waters, 1981-1991.

EVALUATION OF SEA SAMPLING DESIGN

The goal of this long term American lobster monitoring program is to collect data with adequate precision for stock assessments and to evaluate management changes. Due to data needs of various analytical applications it is necessary to not only provide standardized survey indices but characterize commercial landings with biological data. Accordingly, the sample design comprises both survey and sea sampling strategies and has a standardized, fishery-dependent approach. The twelve years of data generated by the program have been used extensively for various methods of lobster assessment, results from 1981-1986 summarized by Estrella and McKiernan 1989, 1981-1991 data tabulated by Estrella and Cadrin 1992, Idoine et al. 1992a and 1992b). A number of management options at both the DMF and NEFMC level have been evaluated with this data base. In recent years the National Marine Fisheries Service and the states of Maine, New Hampshire, and Rhode Island have augmented their research programs with similar lobster sea sampling strategies. Discussions held by the lobster scientific committee of the Atlantic States Marine Fisheries Commission in March 1992 regarding standardization of lobster sampling procedures suggested the DMF sea sampling design as a model for those states inclined to develop commercial catch monitoring programs at sea.

Approximately 80% of Massachusetts coastal commercial landings are harvested in the six regions sampled; 93% landed from May to November (data from McCarron and Hoopes 1992). The current sampling requirements per month per region are two sampling trips of at least 100 trap hauls with a soak time of less than ten days. Four sampling trips per month have been collected in Cape Cod Bay due to a concern for its large area, 38% of sampling area. The current level of sampling requires approximately 196 man-days per year for sea sampling and data transcription. Cooperative fishermen were selected based on their experience and fishing habits (e.g., frequency of fishing, amount of gear, and area fished). The general practice is to sample with one fisherman per region (except Cape Cod Bay and outer Cape Cod where sampling is generally with two fishermen each month).

Analytical procedures are contingent on the application of estimates. Annual survey indices (e.g., standardized catch per trap haul, ovigerous catch per trap haul, cull rate, trap mortality) are derived from a weighting scheme in which months contribute equally (i.e., are statistically adjusted to have equal sample size), and regional data are weighted according to the proportion of total area (n mi^2) in each region (Estrella 1983). Characterization of landings (e.g., for cohort analysis) involves expanding data to landings by month and region (Estrella and Cadrin 1992).

In April 1992, the DMF administration requested a formal review of the sea sampling protocol to decide if acceptable precision could be achieved at lower levels of sampling. A panel of researchers from the National Marine Fisheries Service (NMFS), Northeast Fishery Science Center (NEFSC) conducted a program review and made several suggestions for analysis (Overholtz et al. 1992). Recommendations of Overholtz et al. (1992) and an evaluation of reductions in sampling intensity are hereby addressed. The general approach has been to estimate the effect of sample reduction on three key indices: standardized catch per trap haul (CTH'_3), ovigerous catch per trap haul (CTHAUL), and mean carapace length (CL) of marketable lobster.

Estimating Variance of Catch Rates

Accurate estimates of variance are crucial to determining adequate sample size for each parameter. Conventional estimates of variance may be biased because the sampling scheme is a clustered design, and trips, trawls of traps, and individual traps may have discrete levels of variance. CTH'_3 and CTHAUL estimates reported by the program are based on trap hauls as sampling units (i.e., they are arithmetic means [$\mu=\Sigma y/n$] with conventional sample variances [$s2=\Sigma(y-\mu)2/(n-1)$], where y is catch in each trap and n is total number of traps). Program reviewers suggested an investigation of alternative sampling units (e.g., trips or trawls of traps) to estimate catch rates and their variance. Consequently, ratio estimator methods were used to compute catch rates as the quotient of total catch (Σy; standardized number of marketable lobster for CTH'_3 or number of ovigerous lobster for ovigerous CTHAUL) divided by total trap hauls (Σx). Although the catch rate estimates from the two methods were equal ($\mu = \Sigma y/\Sigma x = \Sigma y/n$), estimates of variance were different. Estimates of variance for ratio estimates require 30 sample units and little variation in x and y (e.g., coefficients of variation [$CV=s/\mu$] should be less than 10%; Cochran 1977).

Estimating catch rates for each trip by ratio methods was not possible because very few sampling trips in the time series consisted of 30 trawls. Also, no region had 30 trips sampled per year to estimate annual regional ratio estimates. As an exercise to better estimate true variance, ratio estimates of annual CTH'_3 were computed for the southern Gulf of Maine regions (Cape Ann to Cape Cod Bay) for the years 1983-1991, where number of trips per year ranged from 30 to 68. CVs for standardized number of marketable lobster (24-41%) and number of trap-hauls (54-77%) were much higher than required. The number of trap-hauls and, indirectly, the number of lobster vary due to logistical artifacts (e.g., short trips caused by equipment failure, long trips in preparation for inclement weather, market price), whereas mean catch rate is not subject to the same sources of variance. Estimates of variance and 95% confidence intervals [$CI=2(s/\sqrt{n})tdf,.05$] were substantially higher using ratio methods (mean CI=0.22) than those using conventional methods (mean CI=0.04). In spite of invalidating CV requirements for ratio methods, these results suggest that conventional estimates of catch rate variance are biased low. However, the level of

sampling and nature of the variables does not allow estimation by ratio methods for regional or trip estimates. Therefore, the conventional method of estimating variance was used in this study; this approach assumes that catch rates are homogeneous among clusters within strata (i.e., within months for each region).

Sampling Trip Criteria

Although units of sampling intensity are specific to each parameter being estimated (e.g., number of trap hauls for CTH'_3 and ovigerous CTHAUL, and number of marketable lobster for mean CL), only the number of sampling trips can be completely controlled. The sample design is therefore hierarchical; the higher level involves allocation of sampling trips according to sample variances or the volume of landings used for extrapolation; the lower level involves a determination of n within each trip to insure reasonable confidence of estimates. Although n within trips cannot be directly controlled by the sea sampler, minimum criteria can be used to determine if trips with few observations should be re-sampled.

To determine the relationship of 95% CI to sample size, descriptive statistics of CTH'_3, ovigerous CTHAUL, and marketable CL were computed for each trip from 1981 to 1991. The relationship of CI to n is curvilinear; the slope decreases sharply as n increases from low values, becomes moderate, and levels off asymptotically at high n (Figure 5A-C and Table 1).

These CI estimates can be used to select minimum sample size criteria for trips: choice of minimum acceptable n should be based on predicted confidence and the desired sensitivity of comparisons (i.e., what magnitude difference can be detected): generally, differences of one CI can be detected by parametric tests for equality of means (e.g., t-test or ANOVA). Presuming that there have been some significant parameter differences over time (from 1981-1991) within stocks, ranges of annual estimates can help gauge the magnitude of differences which should be detected. CIs must be a small percentage of the range of annual parameter estimates to allow detection of changes in a time series.

Table 1. 95% confidence intervals of standardized catch per trap haul of marketable lobster (CTH'_3), catch per trap haul (CTHAUL) of ovigerous lobster, and mean carapace length (CL) of marketable lobster by region and sample size predicted from all Massachusetts sea sampling trips 1981-1991. Values in parentheses indicate percent of the mean).

CTH'_3	Southern Gulf of Maine	Outer Cape Cod	Buzzards Bay
# trap hauls			
20	0.34 (81)	0.40 (80)	0.32 (70)
40	0.26 (62)	0.34 (68)	0.26 (57)
60	0.24 (57)	0.28 (56)	0.22 (48)
80	0.20 (48)	0.26 (52)	0.20 (43)
100	0.18 (43)	0.22 (44)	0.18 (39)
120	0.18 (43)	0.20 (40)	0.18 (39)
Ovigerous CTHAUL			
# trap hauls			
20	0.10 (323)	0.18 (120)	0.26 (70)
40	0.08 (258)	0.16 (107)	0.22 (59)
60	0.08 (258)	0.14 (93)	0.20 (54)
80	0.06 (194)	0.12 (80)	0.18 (49)
100	0.06 (194)	0.10 (67)	0.16 (43)
120	0.06 (194)	0.10 (67)	0.16 (43)
Mean CL (mm)			
# marketable lobster			
20	4.0 (5)	9.0 (9)	3.4 (4)
40	3.0 (3)	7.0 (7)	2.8 (3)
60	2.6 (3)	6.0 (6)	2.4 (3)
80	2.0 (2)	5.0 (5)	2.0 (2)
100	1.8 (2)	4.6 (5)	1.8 (2)
120	1.6 (2)	4.2 (4)	1.6 (2)
140	1.4 (2)	4.0 (4)	1.4 (2)
160	1.2 (2)	3.8 (4)	1.2 (1)

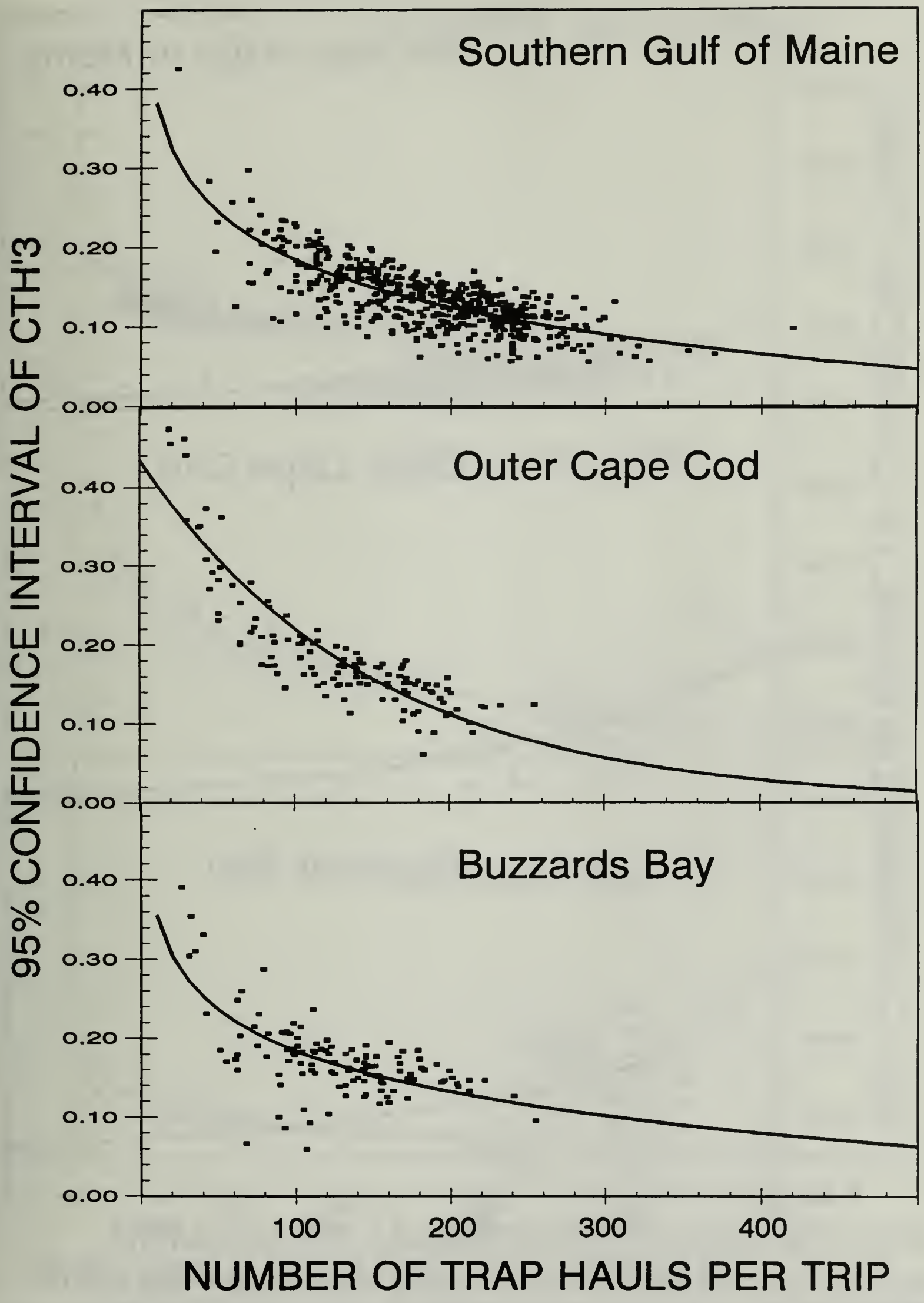


Figure 5A. 95% confidence intervals of standardized catch per trap haul from commercial lobster trap sampling trips in Massachusetts coastal waters 1981-1991.

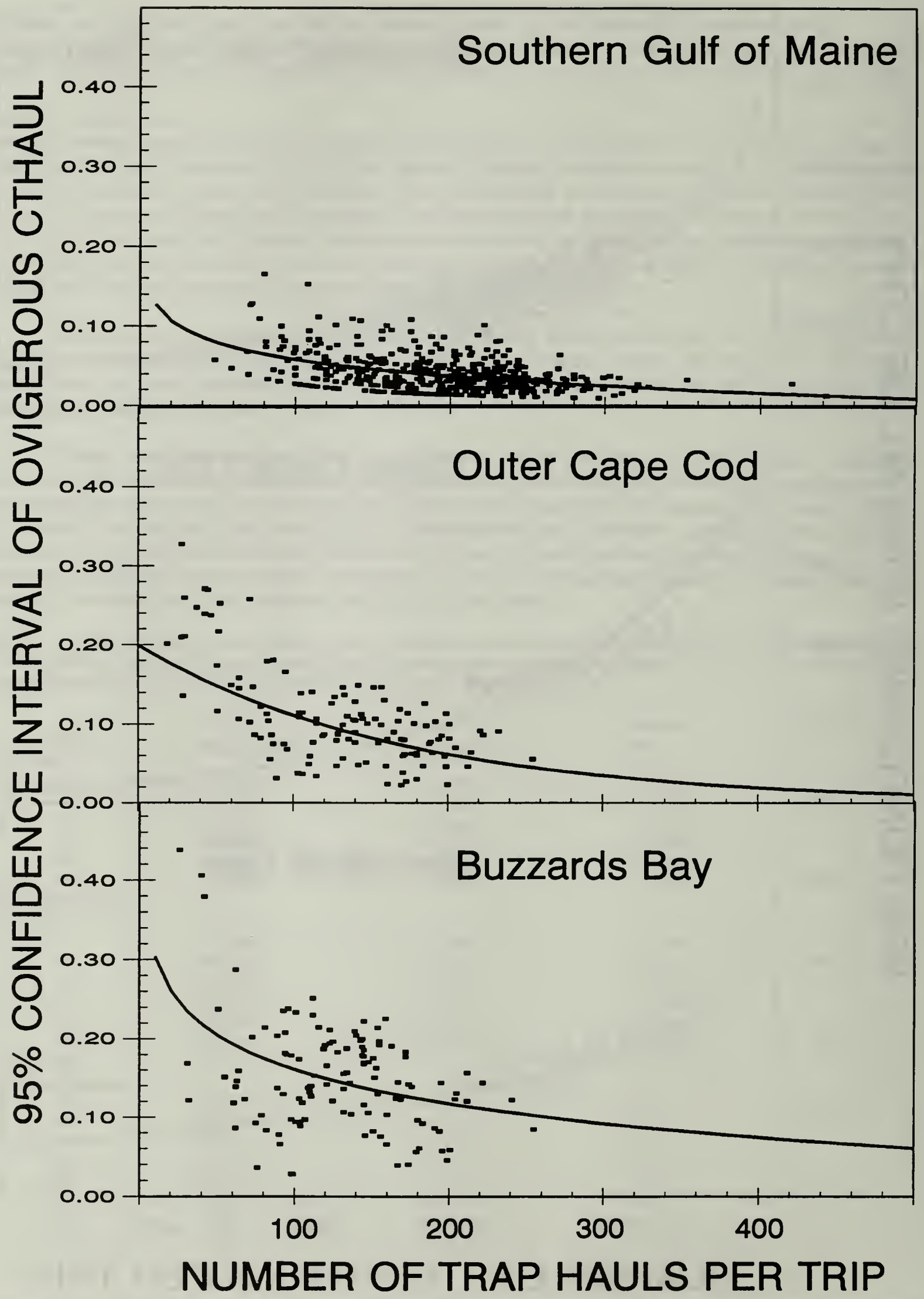


Figure 5B. 95% confidence intervals of ovigerous catch per trap haul from commercial lobster trap sampling trips in Massachusetts coastal waters 1981-1991.

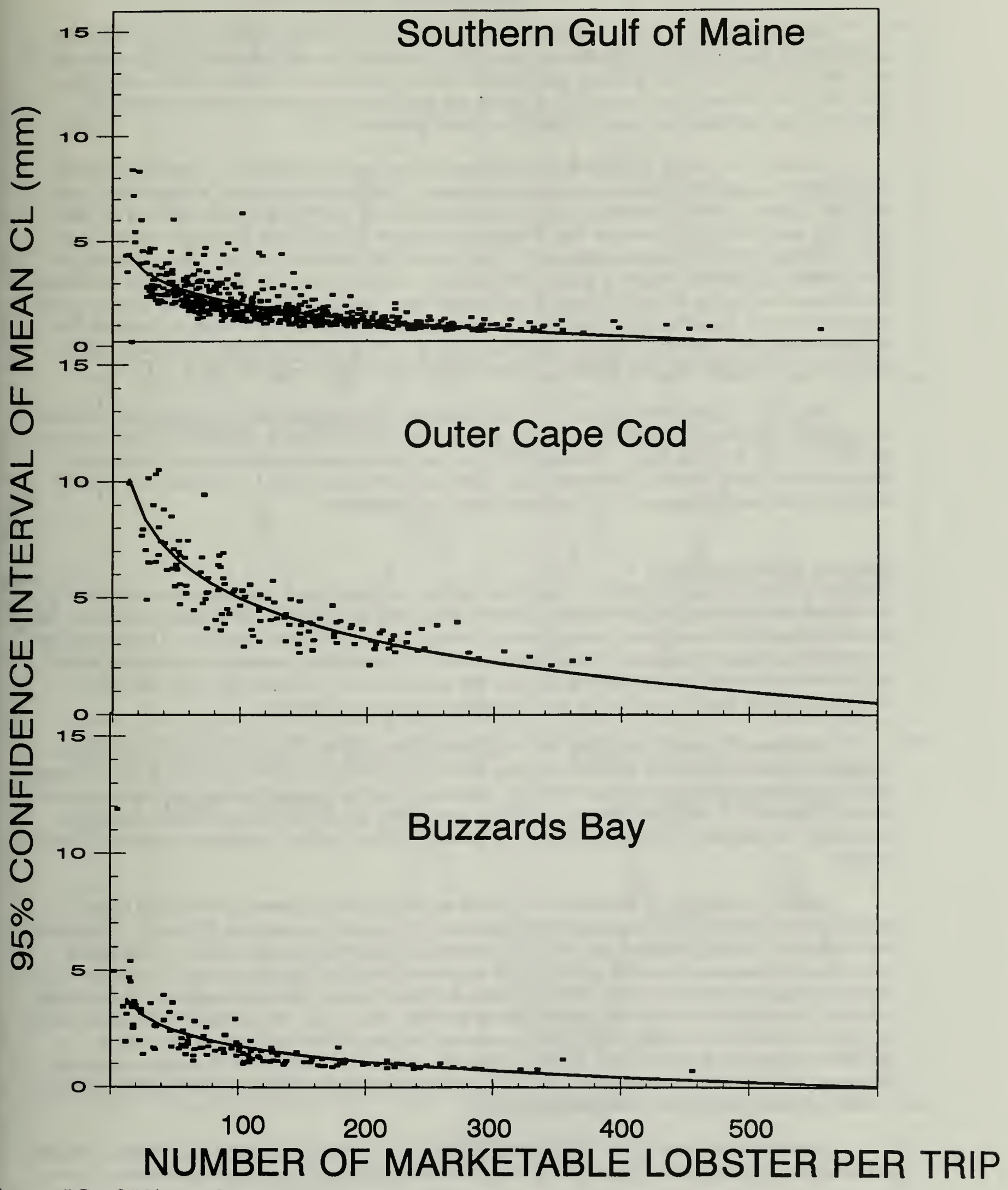


Figure 5C. 95% confidence intervals of mean carapace length per trap haul from commercial lobster trap sampling trips in Massachusetts coastal waters 1981-1991.

Annual estimates of CTH'_3 range from 0.5-1.3 for the Gulf of Maine, 0.6-1.2 for outer Cape Cod, and 0.6-1.1 for Buzzards Bay. A 0.2 difference in CTH'_3 (25-40% of the total range) can be achieved with 80 trap hauls per trip in the Gulf of Maine and Buzzards Bay and with 120 trap hauls per trip in outer Cape Cod. Note that 100 trap hauls in the Gulf of Maine and Buzzards Bay insures detection of 0.18 CTH'_3 differences, and increasing trap hauls to 120 has negligible decrease in CI.

Unlike CTH'_3, which is relatively homogeneous among regions, magnitude of ovigerous CTHAUL has substantial geographic differences in mean and variance. For years with constant minimum legal size (1981-1987) annual estimates of ovigerous CTHAUL were 0.01-0.05 for Gulf of Maine, 0.08-0.24 for outer Cape Cod, and 0.14-0.83 for Buzzards Bay. Detecting differences in catch rates of ovigerous lobster in the Gulf of Maine is difficult because catches were so low; even at 120 trap hauls per trip, only differences of 0.06 (greater than the total range) or greater are significant. Ovigerous catch in outer Cape Cod was higher, and CIs were low enough so that a 0.10 (40% of the total range) or larger difference can be detected at 100 trap hauls per trip; increasing to 120 trap hauls has negligible benefit. Ovigerous catches in Buzzards Bay are high enough that, even with high CIs, differences of 0.18 (27% of the total range) and greater can be detected at 80 trap hauls per trip; increasing trap hauls beyond 100 has a negligible effect on CI.

Mean CL of marketable lobster is also heterogeneous among regions and very stable within regions (for 1981-1987, the range in mean CL was 86-89 mm for the Gulf of Maine, 95-100 mm for outer Cape Cod, and 85-86 mm for Buzzards Bay). Differences of 2 mm and greater can be detected with 80 marketable lobster for the Gulf of Maine and Buzzards Bay. However, for the outer Cape Cod region, even with 160 lobsters per trip, only differences of 3.8 mm and greater are significant.

Evaluation of Quarterly Design

One approach to reducing the number of sampling trips per year is to change the temporal sampling design. The current monthly strata design requires that seven strata, May to November, be adequately sampled. In a quarterly design, only three strata (spring, summer, and autumn) need adequate sampling. The disadvantage to quarterly sampling is that temporal resolution is coarser (i.e., parameter changes occuring within months may not be represented). Such weighting assumes that parameters are homogeneous within quarters (i.e., weighting the same data by month or by quarters produces the same estimate).

The effect of quarterly weighting was evaluated by comparing the estimates produced by quarterly weighting to those derived from monthly weighting without a reduction in number of sampling trips. Annual regional estimates of CTH'_3, ovigerous CTHAUL, and mean CL were computed as the weighted average of quarterly estimates. A weighting scheme of 2:3:2 for spring (May and June), summer (July, August, and September), and autumn (October and November), respectively, was used to approximate equal weighting of months.

One way of viewing the comparisons of annual regional estimates between monthly and quarterly weighting is an overlay of the time series of estimates and CIs from the two methods (Figure 6). Confidence intervals indicate the range comprising 95% of all estimates produced by a similar method. Therefore, if parameters are homogeneous within quarters, 95% of quarterly weighted estimates should be within the CIs of monthly weighted estimates. Two CTH'_3 estimates are clearly outside the confidence intervals of monthly estimates (Beverly/Salem in 1981 and Boston Harbor in 1984). Both cases with significant differences can be explained by insufficient sampling: there were no summer samples for Beverly/Salem in 1981 and no November samples for Boston Harbor in 1984. State-wide estimates of CTH'_3 by both weighting methods are presented in Figure 7. Excluding 1981, which is highly affected by the Beverly/Salem estimate, only one (1990) of ten falls outside the monthly-weighted CIs.

Another way of viewing these comparisons is a frequency histogram of differences between estimates and mean confidence intervals (Figure 8A-C). The two outliers, Beverly/Salem in 1981 and Boston Harbor

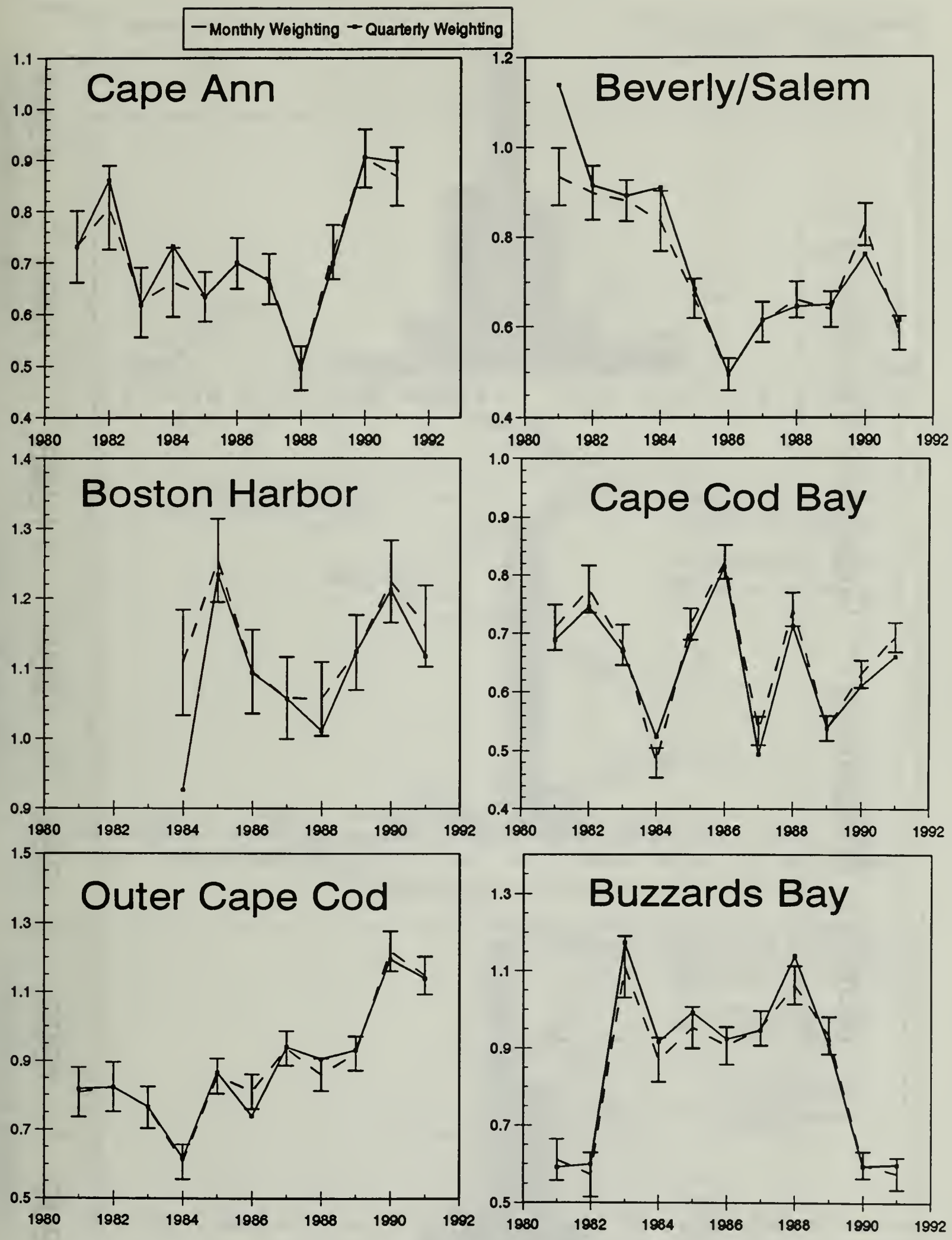


Figure 6. Standardized catch per trap haul by region using monthly weighting and quarterly weighting. Error bars indicate 95% confidence of monthly weighted estimates.

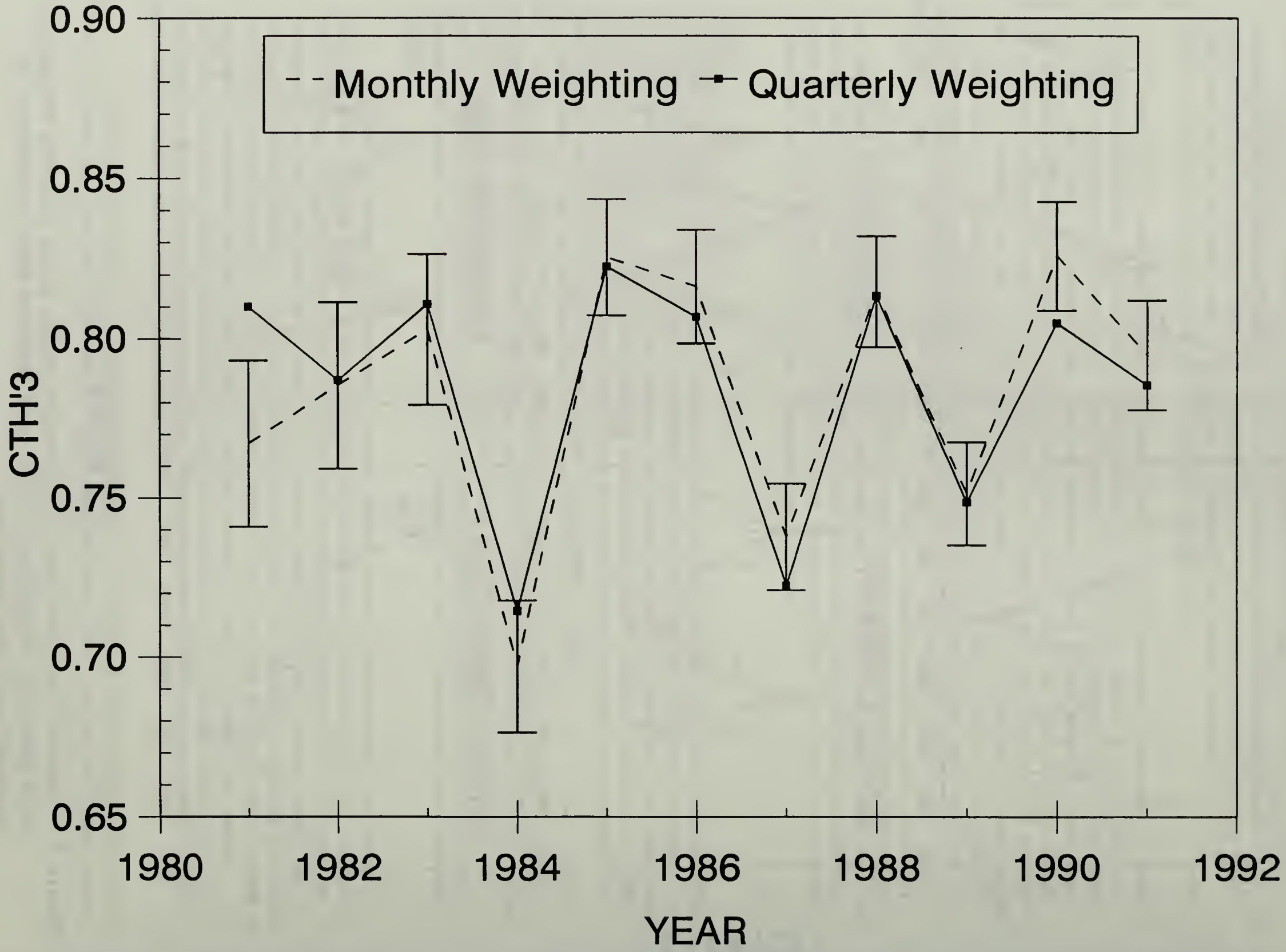


Figure 7. Standardized catch per trap haul for all Massachusetts waters using monthly weighting and quarterly weighting. Error bars indicate 95% confidence of monthly weighted means

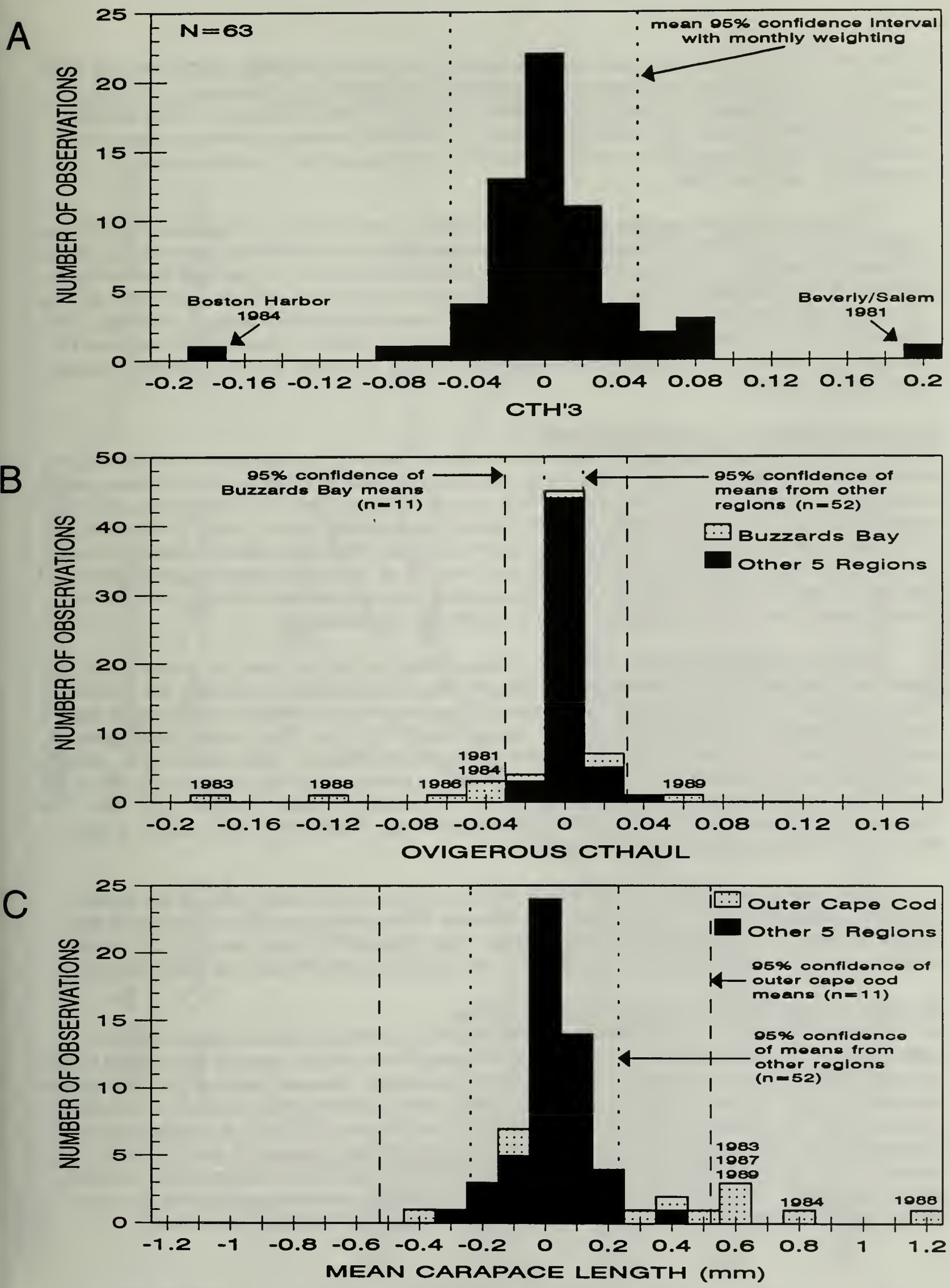


Figure 8. Difference in marketable catch rate (A), ovigerous catch rate (B), and mean carapace length (C) between monthly and quarterly weighting.

in 1984, are indicated by large differences between monthly and quarterly weighting in Figure 8A. All other differences in CTH'_3 estimates are symmetrically distributed around zero (which indicates no difference between the two methods). Excluding the two outliers, seven of 61 (11%) differences in CTH'_3 between monthly and quarterly weighting are outside the mean CI. Given the proximity of quarterly estimates to monthly CIs and the conservative bias of CIs due to cluster sampling, quarterly weighting is probably acceptable for estimating CTH'_3.

Differences between quarterly-weighted and monthly-weighted estimates of ovigerous CTHAUL are depicted in Figure 8B. Quarterly-weighted estimates are acceptable for all regions but Buzzards Bay. Figure 8C illustrates comparisons of quarterly-weighted and monthly-weighted mean CL; estimates for outer Cape Cod were significantly different. It is clear that seasonal trends in ovigerous catch rates in Buzzards Bay and mean CL in outer Cape Cod are highly variable and are not homogeneous within quarters. Although CTH'_3 can be adequately sampled for with a quarterly design, ovigerous CTHAUL in Buzzards Bay and mean CL for outer Cape Cod can not. Therefore, if the latter estimates are considered important, quarterly sampling should not be adopted.

Reduction of Sampling Trips to One per Month

Another strategy to reduce sampling intensity is to decrease the number of sampling trips per region per month from two to one. Reduction to one trip per month was assessed by selecting subsets of data to derive estimates and comparing them to the estimates from all data. All regions and years with two trips for all seven months (Cape Ann in 1985, 1988, and 1990; Beverly/Salem in 1990; Boston Harbor in 1985, 1989, and 1990; outer Cape Cod in 1988; and Buzzards Bay in 1985, 1989, and 1990) were selected to simulate annual regional estimates of CTH'_3, ovigerous CTHAUL, and mean CL of marketable lobster for all possible combinations of one trip per month ($2^7=128$). Because there were no years in which there were two trips for each month from Cape Cod Bay, that region is omitted from these analyses.

Frequency distributions of the 128 CTH'_3 estimates from one trip per month for each year and region were compared to the estimates and CIs using all data to assess stability of estimates with reduced sampling. Estimates of CTH'_3 from all regions except Cape Ann were very unstable (e.g., subsets of data from Boston Harbor in 1985 produced estimates ranging from 0.98 to 1.54). The frequency distributions of ovigerous CTHAUL also show that estimates based on one trip per month are highly variable (e.g., estimates for Buzzards Bay in 1990 ranged from 0.74 to 1.82). Mean CL estimates were also unstable especially in the Cape Ann (e.g., 1990 estimates ranged from 90 to 92 mm CL) and outer Cape Cod regions (e.g., 1988 estimates ranged from 95.4 to 98.2 mm CL). The instability of outer Cape Cod in 1988 estimates is partly due to trips with few marketable lobster sampled.

Although reducing sampling effort to one trip per month per region would decrease the current manpower requirements from 196 to 84 man-days, estimates of size distributions for outer Cape Cod and catches of ovigerous females in Buzzards Bay and outer Cape Cod would be highly unstable. If twice the sampling effort is maintained for Cape Cod Bay (i.e., two trips per month), 98 man-days would be required.

Reduction of Sampling Trips - Seasonal Allocation of Trips

An alternative to reducing a monthly sampling scheme by half is to allocate trips according to seasonal patterns in landings and parameter variance. It may be appropriate to allocate sampling according to trends in landings because data are expanded to landings for certain analyses. Seasonal trends of 1991 landings vary regionally, but generally increase from low values in spring, reach a maximum in the summer, and decline in autumn (Figure 9). Seasonal patterns in variance of CTH'_3 and ovigerous CTHAUL are similar to those in landings; they are most variable in summer. There is no seasonal trend in variance of mean CL within regions. Thus, the most appropriate allocation of sampling effort should be low in spring, high in summer, and low in autumn. A secondary benefit of this scheme would be that reductions occur during the most difficult months to schedule sampling trips due to inclement weather and irregular fishing effort.

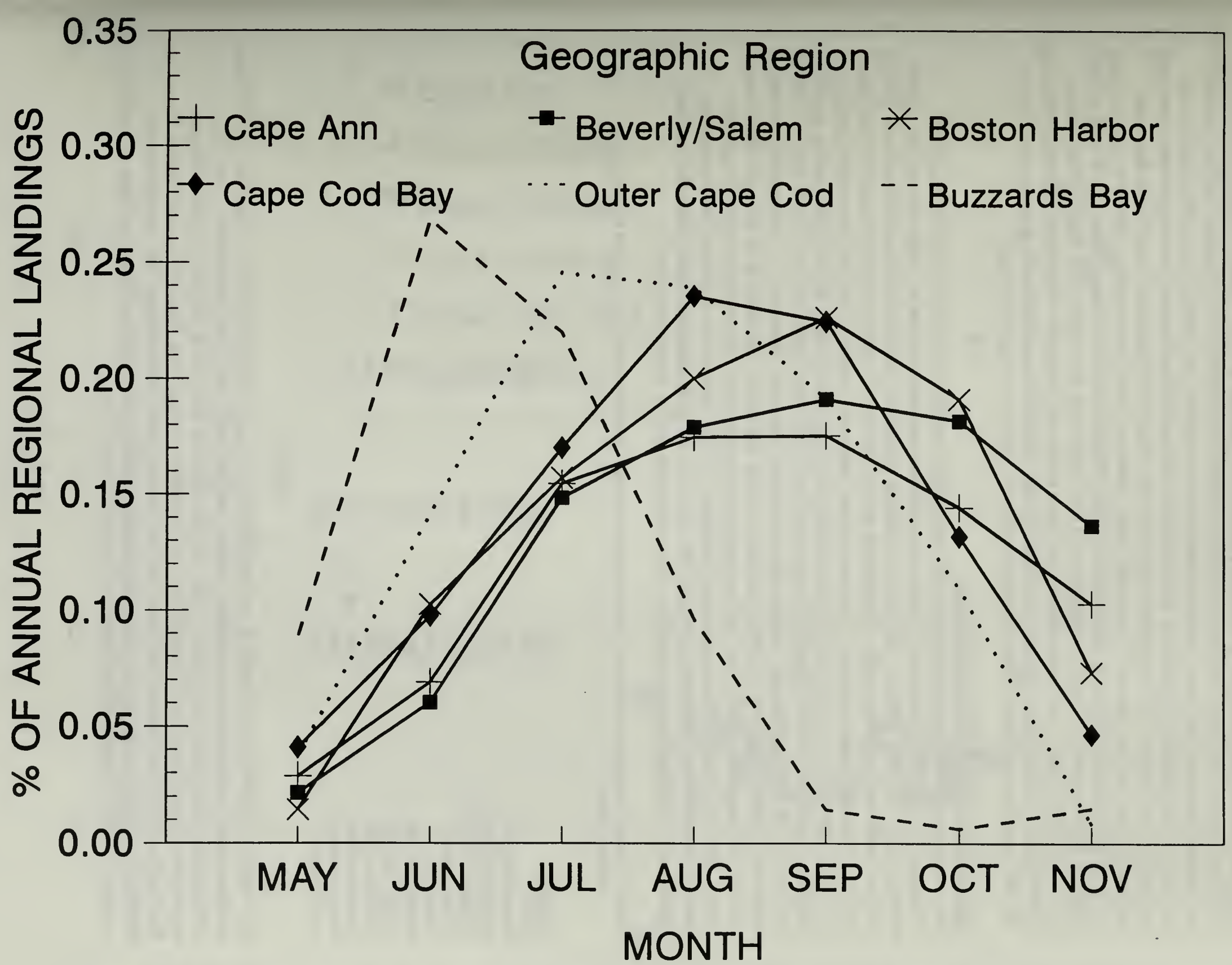


Figure 9. Lobster landings from Massachusetts territorial waters 1991 by month and region. Data from McCarron and Hoopes (1992).

Similar to the previous analysis (i.e., evaluation of one trip per month), subsets of existing data were selected to investigate the effects of seasonal reductions in number of trips. Annual regional estimates of CTH'_3, ovigerous CTHAUL, and mean CL were simulated using the following seasonal sampling scheme: one trip per month in May, June, October, and November and two trips per month in July, August, and September. All possible combinations of this sampling scheme were calculated from regions and years with two trips for each month ($2^4=16$ possible combinations). These estimates were more stable than those produced by one trip per month for the entire year. However, some estimates were clearly out of the range of CIs derived from all trips (e.g., ovigerous CTHAUL in outer Cape Cod ranged from o.14 to 0.23 in 1988, Buzzards Bay ovigerous CTHAUL ranged from 0.8 to 1.7 in 1990, and mean CL in Buzzards Bay ranged from 85.5 to 87 in 1991). Although samples are more stable with seasonal reductions than overall reductions in number of trips per month, manpower savings are less (required man-days would decrease from 196 to 120; 140 man days would be needed if twice the effort is allocated to Cape Cod Bay).

Evaluation of Realigning Geographic Strata

The program reviewers recommended that the geographic stratification scheme should be examined. Evaluating the relative importance of strata for population estimates involves an assessment of homogeneity among regions for many indices. Estimates of eighteen population parameters for each region from 1981 to 1991 are tabulated in the Appendix. Multivariate analysis of these parameters was performed to investigate patterns of variation and covariation in annual regional estimates (n=63). Principal components analysis (PCA) is a descriptive statistical method of resolving information from many variables into few by deriving weighted combinations of variables (i.e., components; PC1, PC2, etc.) based on their correlations. An initial PCA run on all nineteen variables showed discrete regional patterns. However, PC1 was generally based on catch rates of sublegal lobster and PC2 was based on four cull rates. Estimates from sublegal-lobster and cull rates accounted for 37% of the total variance; because they were not considered highly important indices, they were excluded from subsequent analyses. A PCA based on the remaining twelve variables produced three components which accounted for 88.4% of the total variance. Table 2 lists the 'loadings' (defined as correlations between variables and components) of the eleven variable PCA.

Table 2. Principal component loadings for 12 annual regional population estimates.Bold loadings are used for component interpretations.

Variable	PC1	PC2	PC3
CTH'_3	-.07	0.12	**0.93**
Percent Ovigerous	-.29	**0.94**	0.03
Ovigerous CTHSOD	0.29	**0.87**	0.21
Ovigerous CTHAUL	0.17	**0.92**	0.20
Fishing Pressure	**0.97**	-.18	-.01
Gulland's Z	**0.83**	0.22	0.07
Beverton & Holt's Z	**0.95**	0.15	-.12
Fishing Mortality	**0.98**	0.04	-.03
Exploitation Rate	**0.95**	-.20	0.08
Marketable Mean CL	**-.96**	0.12	0.04
Ovigerous Mean CL	**-.94**	-.03	-.06
Trap Mortality	-.18	0.65	-.29

PC1 explained 52.6% of total variance and was interpreted as size distribution; PC2 accounted for 25.9% and was interpreted as abundance of ovigerous lobster; and PC3 had 8.6% of the total variance and was interpreted as marketable catch rate. A plot of PC2 scores on PC1 scores (Figure 10) shows discrete separation of outer Cape Cod, Buzzards Bay, and to a lesser extent Cape Ann. Score distributions for Beverly/Salem, Boston Harbor, and Cape Cod Bay overlap, which indicates that size distribution and abundance of ovigerous lobster are relatively homogeneous for these regions. Cluster analysis of the same variables (Table 3) supported the separation produced by the PCA.

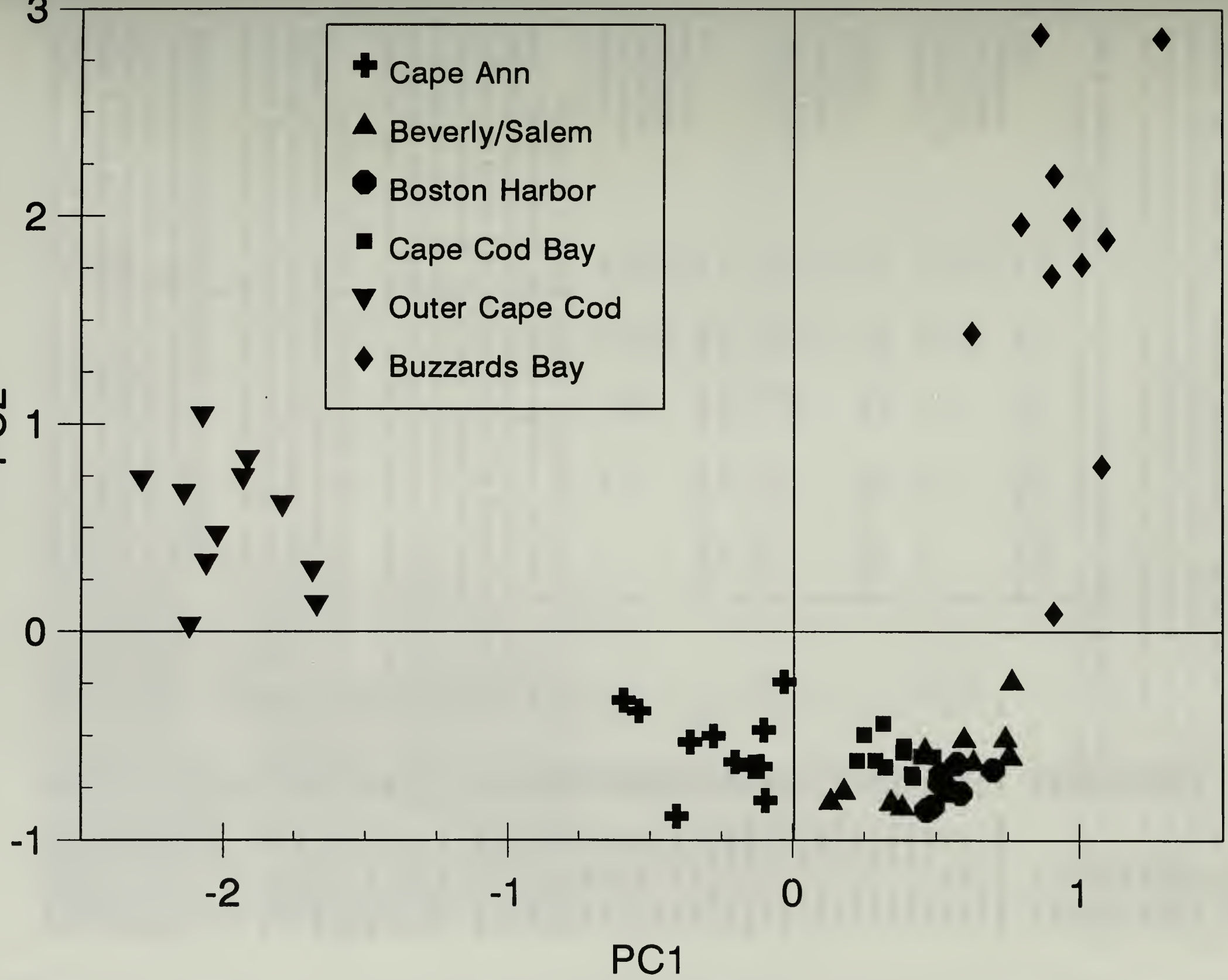
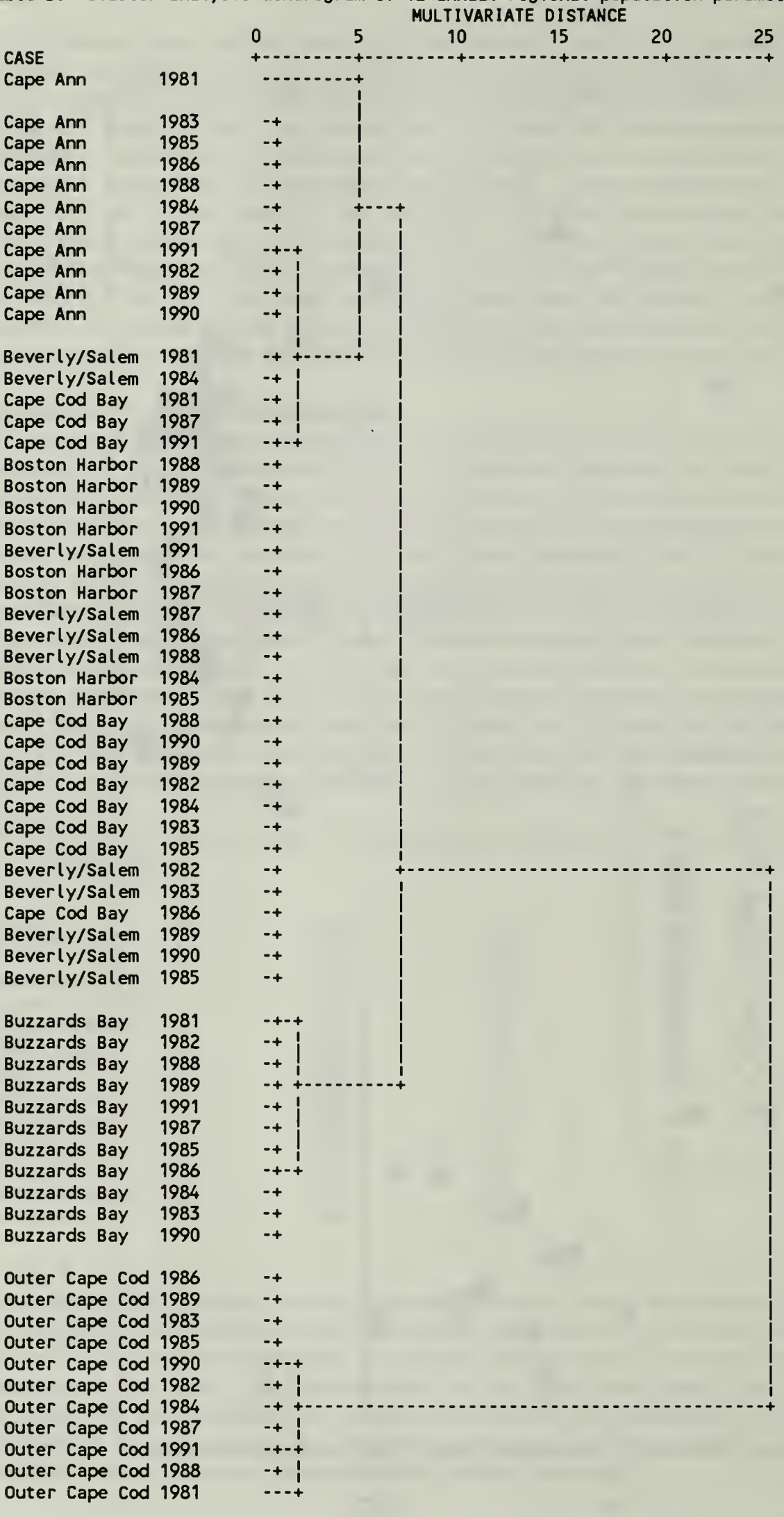


Figure 10. Principal component scores by region from principal components analysis of 12 population parameter estimates.

Table 3. Cluster analysis dendrogram of 12 annual regional population parameters.



The differences among regions in annual estimates indicated by the multivariate methods was supported by univariate tests of monthly estimates (n=77) of the same general indices. Probabilities of matched pairs comparisons (i.e., Wilcoxon sign rank tests) of regional monthly CTH'_3, ovigerous CTHAUL, and mean CL of marketable lobster are presented in Table 4. Beverly/Salem accounted for four of the ten homogeneous comparisons; the Beverly/Salem region has homogeneous CTH'_3 with Cape Ann and Cape Cod Bay; homogeneous CTHAUL with Boston Harbor; and homogeneous mean CL with Cape Cod Bay.

Table 4. Probabilities of pairwise Wilcoxon sign rank tests among regions for monthly marketable catch rate (CTH'_3), ovigerous catch per trap haul (CTHAUL), and mean carapace length of marketable lobster (CL); * denotes homogenous regions.

CTH'_3	Cape Ann	Beverly /Salem	Boston Harbor	Cape Cod Bay	Outer Cape Cod
Beverly/Salem	0.25*				
Boston Harbor	0.00	0.00			
Cape Cod Bay	0.24*	0.32*	0.00		
Outer Cape Cod	0.00	0.00	0.02	0.00	
Buzzards Bay	0.01	0.02	0.02	0.01	0.39*

CTHAUL	Cape Ann	Beverly /Salem	Boston Harbor	Cape Cod Bay	Outer Cape Cod
Beverly/Salem	0.00				
Boston Harbor	0.14*	0.20*			
Cape Cod Bay	0.19*	0.01	0.66*		
Outer Cape Cod	0.00	0.00	0.00	0.00	
Buzzards Bay	0.00	0.00	0.00	0.00	0.00

CL	Cape Ann	Beverly /Salem	Boston Harbor	Cape Cod Bay	Outer Cape Cod
Beverly/Salem	0.00				
Boston Harbor	0.00	0.01			
Cape Cod Bay	0.00	0.30*	0.37*		
Outer Cape Cod	0.00	0.00	0.00	0.00	
Buzzards Bay	0.00	0.00	0.00	0.00	0.00

The pattern of regional differences of population estimates reflects the structure of regional lobster stocks. The Massachusetts coastal fishery subsists on up to three discrete stocks. Approximately 92% of 1991 Massachusetts territorial landings were from the Gulf of Maine (statistical areas 1-8 in Figure 11 from McCarron and Hoopes 1992), 5% from southern New England (statistical areas 12-14), and 3% from a transition zone between the Gulf of Maine, Georges Bank/Offshore, and southern New England stocks (statistical areas 9-11). Buzzards Bay (statistical area 14) is the most appropriate area to sample within the southern New England statistical areas since it accounts for 51% of territorial landings there. The outer Cape Cod region (statistical area 9) accounts for 96% of landings from the transition zone.

Therefore, maintenance of sampling in Buzzards Bay and outer Cape Cod is justifiable because they represent qualitatively different fisheries. Reduction of sampling effort by pooling or eliminating regions should be done within regions that are relatively homogeneous; multivariate and univariate investigations show that Beverly/Salem, Boston Harbor, and Cape Cod Bay are the most homogeneous regions. For reduction of sampling trips, these three regions could be pooled into two regions.

Reduction in Sampling Effort - Elimination of Beverly/Salem

As mentioned above, allocation of sampling effort should reflect seasonal and geographic patterns in landings and parameter variances. According to patterns in variance, all regions should be sampled with uniform effort; variances were homogeneous (tested by Fmax tests) among all regions for CTH'_3, among all regions except Buzzards Bay for ovigerous CTHAUL, and among all regions except outer Cape Cod for mean CL. Regional patterns of landings and proportions of total area sampled are plotted in Figure 12 (data from McCarron and Hoopes 1992). Among Beverly/Salem, Boston Harbor, and Cape Cod Bay, Beverly/Salem

Figure 11. 1991 Massachusetts Lobster Fishery; Statistical Reporting Map Showing Territorial Waters and Outlying Areas (from: McCarron and Hoopes 1992)

Map produced in cooperation with MassGIS & Dept. of Fisheries, Wildlife and Environmental Law Enforcement's GIS Program.

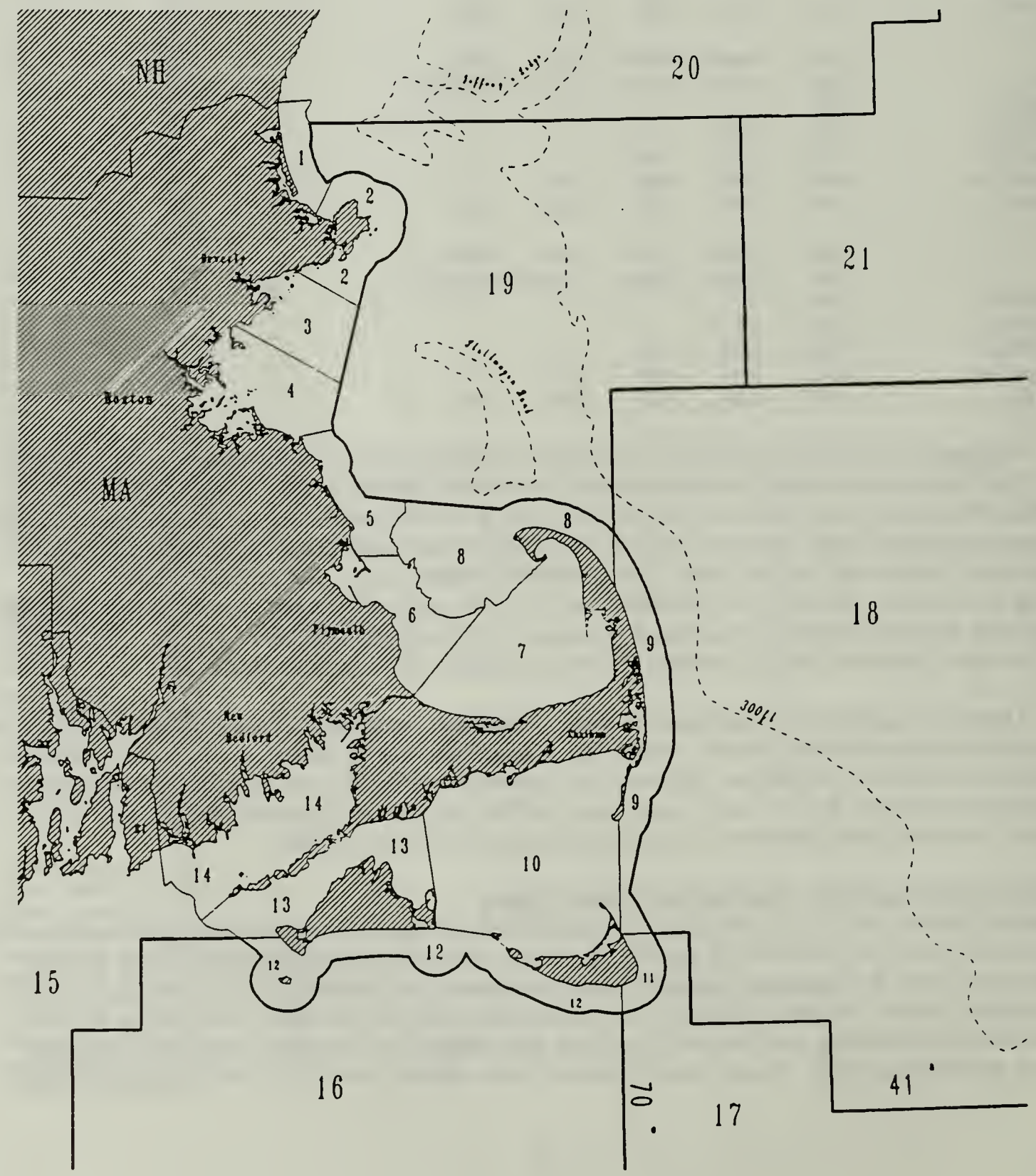
Scale = 1:110,000

0 miles 10 20 30

Description of Boundaries for Territorial Areas

Between Areas	Boundaries
1 & 2	Castle Neck, Ipswich
2 & 3	Coles Point, Manchester
3 & 4	Red Rock, Lynn
4 & 5	Strawberry Point, Cohasset
5 & 6	High Pines Ledge, Plymouth
6 & 7	Scusset Beach, Sandwich
5, 6, 7 & 8	120 Foot Line
8 & 9	70 Degree Longitude Line
9 & 10	70 Degree Longitude Line
9 & 11	41 Degree 20 Minute Longitude Line
10 & 12	Wasque Point, MV to Muskeget Island, Nantucket
10 & 13	Sueconnesset Point, Mashpee to Cape Pogue, MV
11 & 12	70 Degree Longitude Line
12 & 13	41 Degree 20 Minute Longitude Line
13 & 14	Elizabeth Islands and Sow & Pigs Reef to 41 Degree 20 Minute Longitude Line
14 & 15	70 Degree Longitude Line

Areas 1 - 14 = territorial waters.
Parts of area 10 (Nantucket Sound) are federal waters, but are managed by DMF.



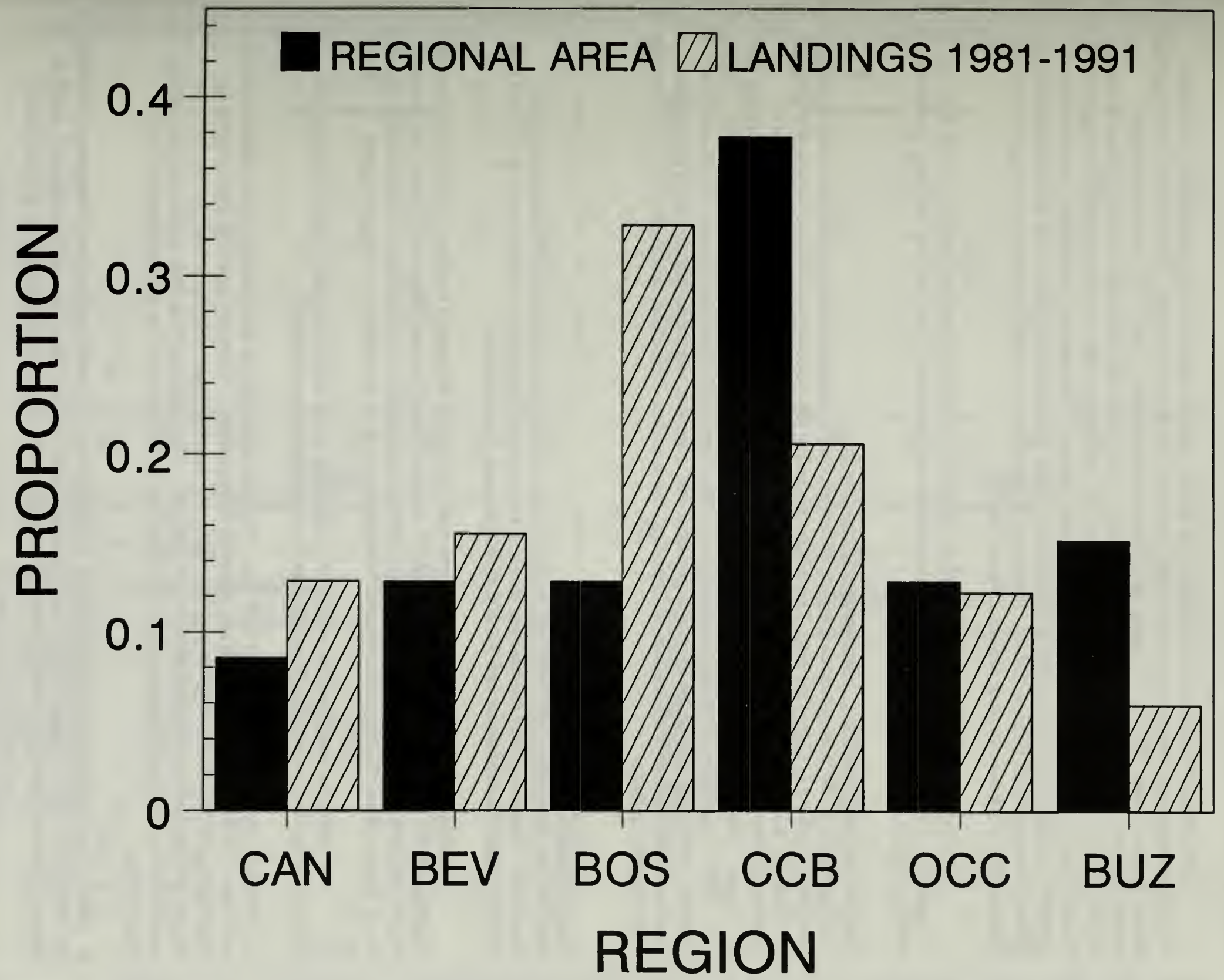


Figure 12. Regional proportions of lobster landings from Massachusetts territorial waters 1981-1991 regional proportions of total area sampled.

has the lowest proportion of landings (i.e., would be expanded the least for analyses such as cohort analysis) and, with Boston, has the smallest proportion of total area.

The effects of pooling Beverly/Salem and Boston Harbor into one strata, represented by Boston Harbor samples, were assessed by regenerating 15 annual population statistics: Figure 13A-H plots statewide annual statistics from 1984 to 1991 using six regions and five regions. All CTH'_3 estimates without Beverly/Salem were significantly higher (Figure 13A). Many sub-legal catch rates were significantly higher (Figure 13B-C), and most estimates of mean CL of sub-legal lobster were significantly higher (Figure 13D) without Beverly/Salem samples; these results suggest regional differences in catchability of small lobster (because of differences in selectivity or abundance). Some ovigerous catch rates were significantly different without Beverly/Salem (Figure 13E-F). Estimates of marketable and ovigerous carapace length were homogeneous between sampling designs (Figure 13G-H).

Although eliminating the Beverly/Salem region would decrease manpower requirements from 196 to 140 man-days (168 man-days if twice the regional effort is allocated to Cape Cod Bay), several population estimates would be significantly effected.

Reduction in Sampling Effort - Elimination of Cape Cod Bay

Another region in the homogeneous complex of Beverly/Salem, Boston Harbor, and Cape Cod Bay which could be eliminated is Cape Cod Bay. The effects of pooling the three regions into one strata and sampling two trips per month in Beverly/Salem and Boston Harbor were assessed by regenerating 15 annual population statistics: Figure 14A-H plots statewide annual statistics from 1984 to 1991 using six regions and five regions. Magnitude and trends of CTH'_3 are severely effected by elimination of Cape Cod Bay (Figure 14A). Other population estimates (sub-legal catch rates, Figure 14B-C; sub-legal mean CL, Figure 14D; ovigerous catch rates, Figure 14E-F; and marketable and ovigerous mean CL, Figure 14G-H) were also significantly different after elimination of Cape Cod Bay samples. Therefore, sampling in the Cape Cod Bay region should continue.

Sample Design Conclusions

Based on the relationships of CIs to trap hauls per trip, the current trip criteria (100 traps per trip) is reasonable. However, when determining the need to re-sample short trips, regional trends in CI/trap haul relations should be considered and Table 1 should be used as a reference.

Quarterly weighting is not acceptable because significant differences between quarterly and monthly weighting of the same data suggests that mean CL in outer Cape Cod and ovigerous CTHAUL in Buzzards Bay are not homogeneous within quarters. Because more estimates were significantly different than expected (much greater than 5%), the assumption of homogeneity of these parameters should be rejected.

All strategies considered for reduction of sampling effort within a monthly sampling design had effects on population estimates. Strategies are listed in order of acceptability:

1. Reducing sampling effort in Cape Cod Bay. Analyses firmly suggest that Beverly/Salem, Boston Harbor, and Cape Cod Bay geographic strata are generally homogeneous. Although Cape Cod Bay samples are weighted heavily due to the large area of the region, the homogeneous complex is sampled by two other regions and population estimates should not be effected. The reduction from four to two trips per month would decrease required manpower from 196 man-days to 168 man-days for sea sampling and data transcription.

2. Seasonal reductions in sampling frequency. Sampling once per month per region in May, June, October, and November, while maintaining two trips per month from July to September, reduces sampling effort in seasons with less landings and lower parameter variance. The effects of such reduction are less stable

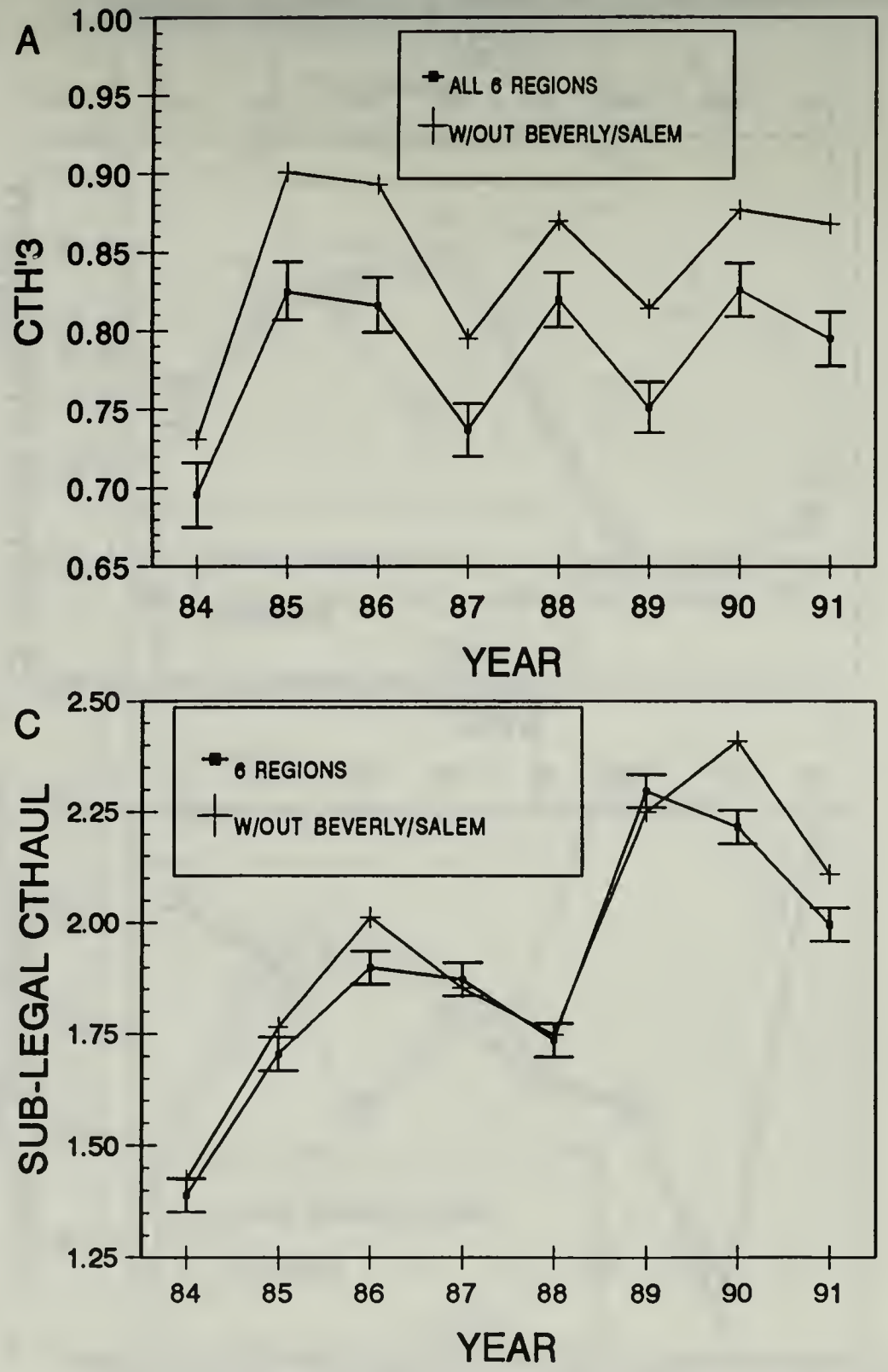
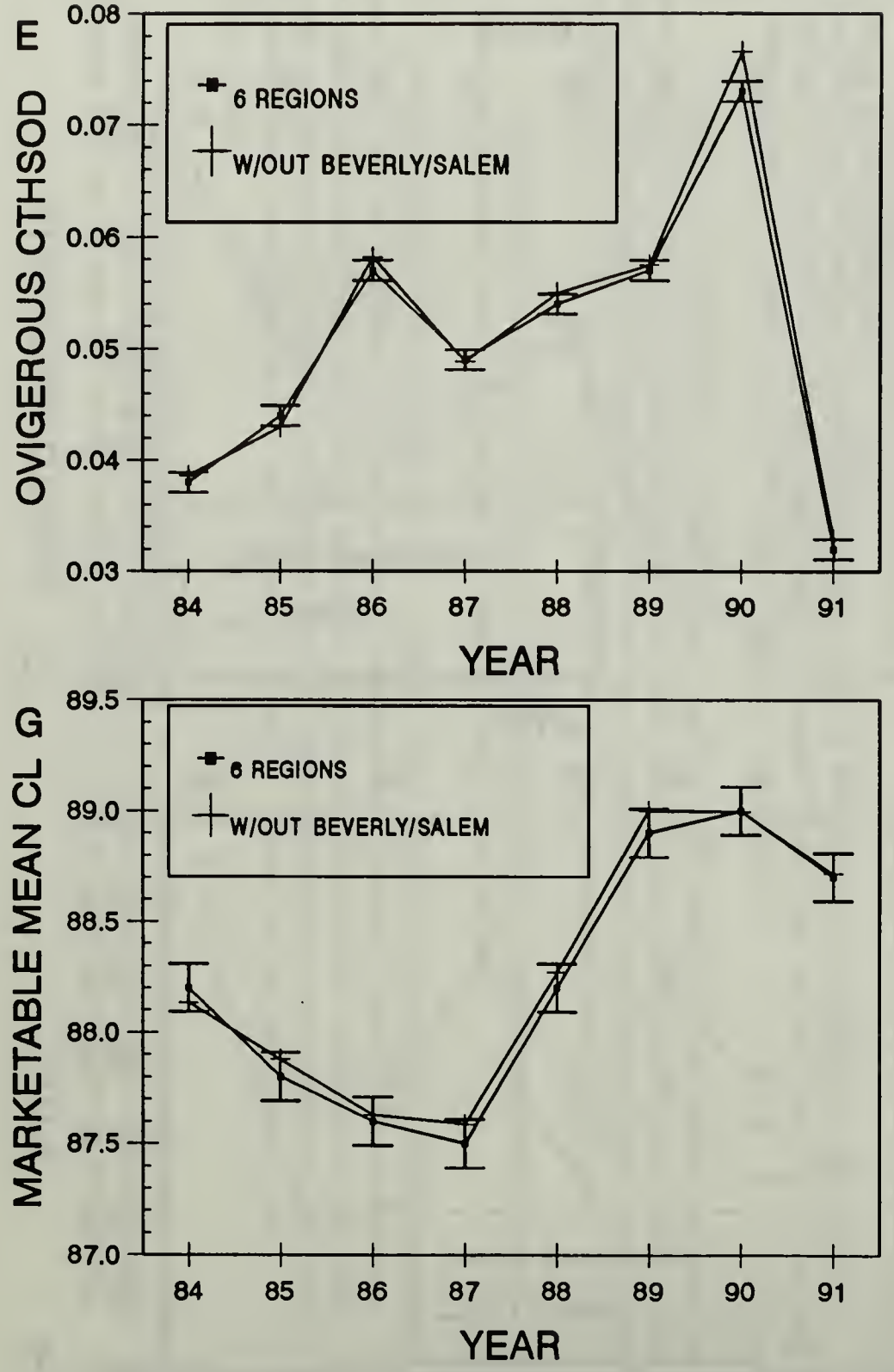


Figure 13. Estimates of standardized catch per trap haul (A), sublegal catch per trap haul set-over-days (B), sublegal catch per trap haul (C), and sublegal mean carapace length (D) using all data and excluding Beverly/Salem data.



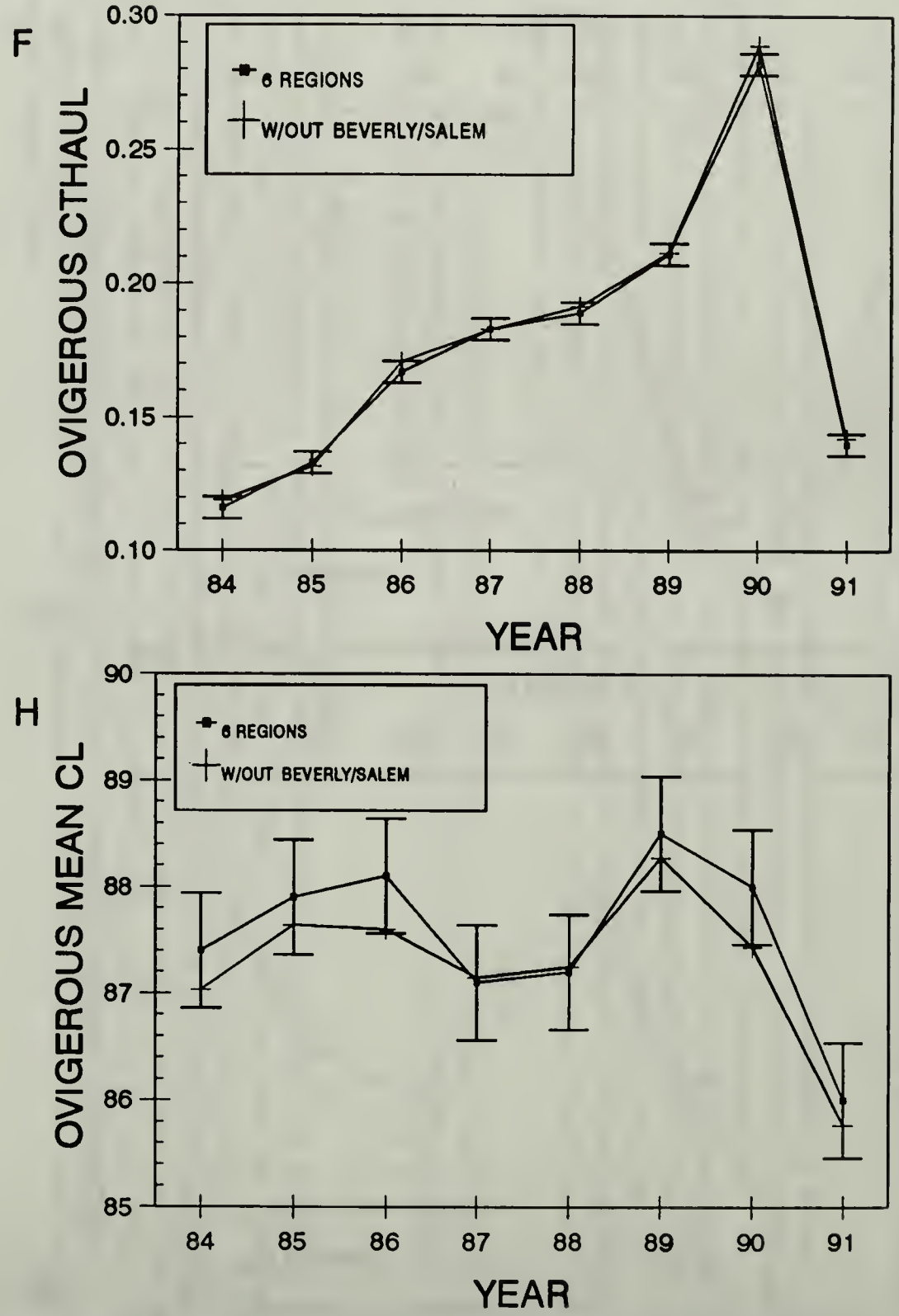
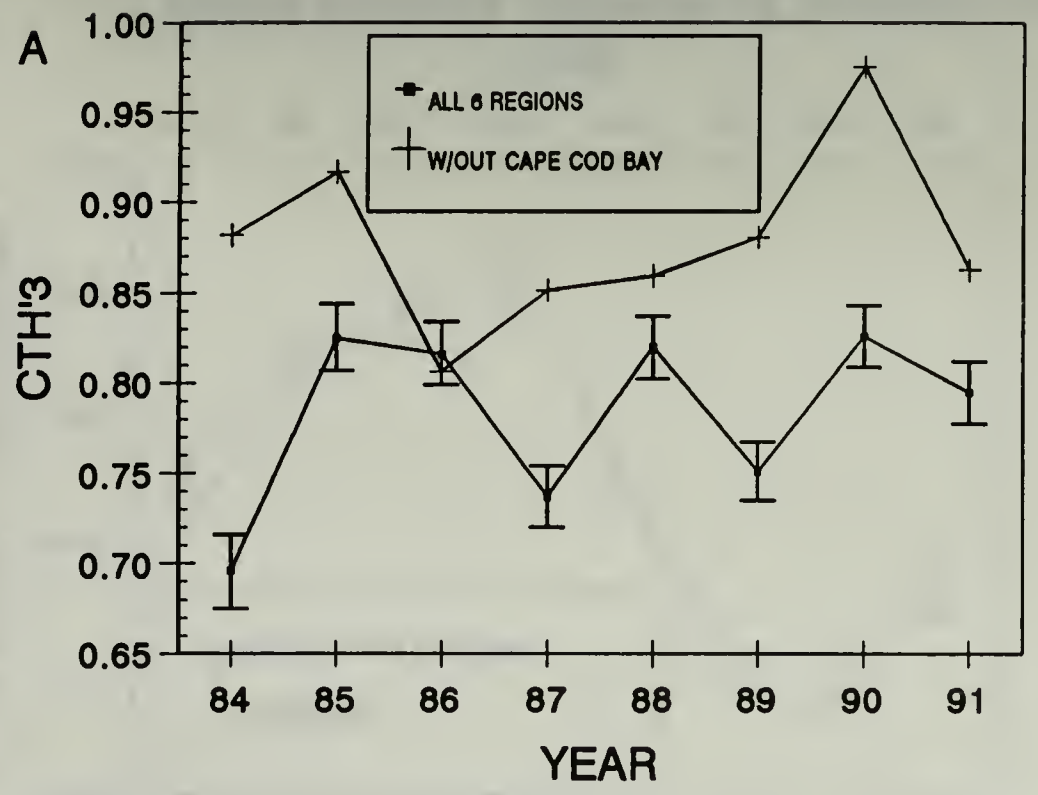
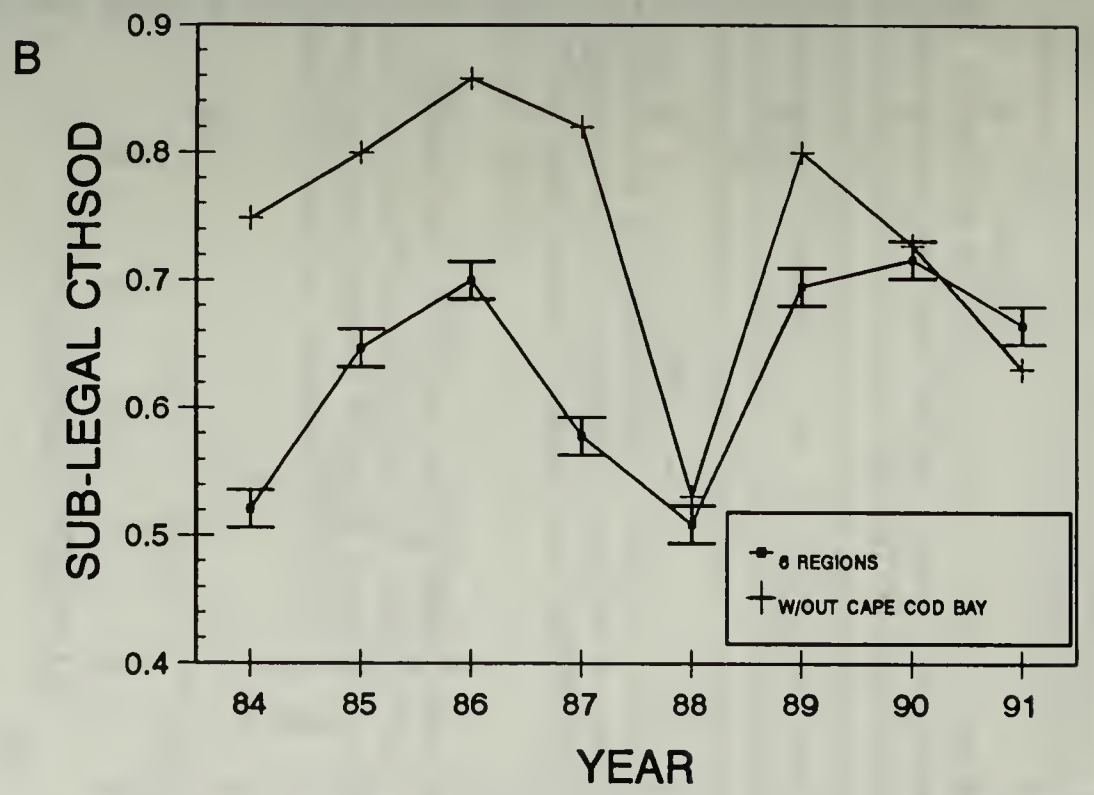
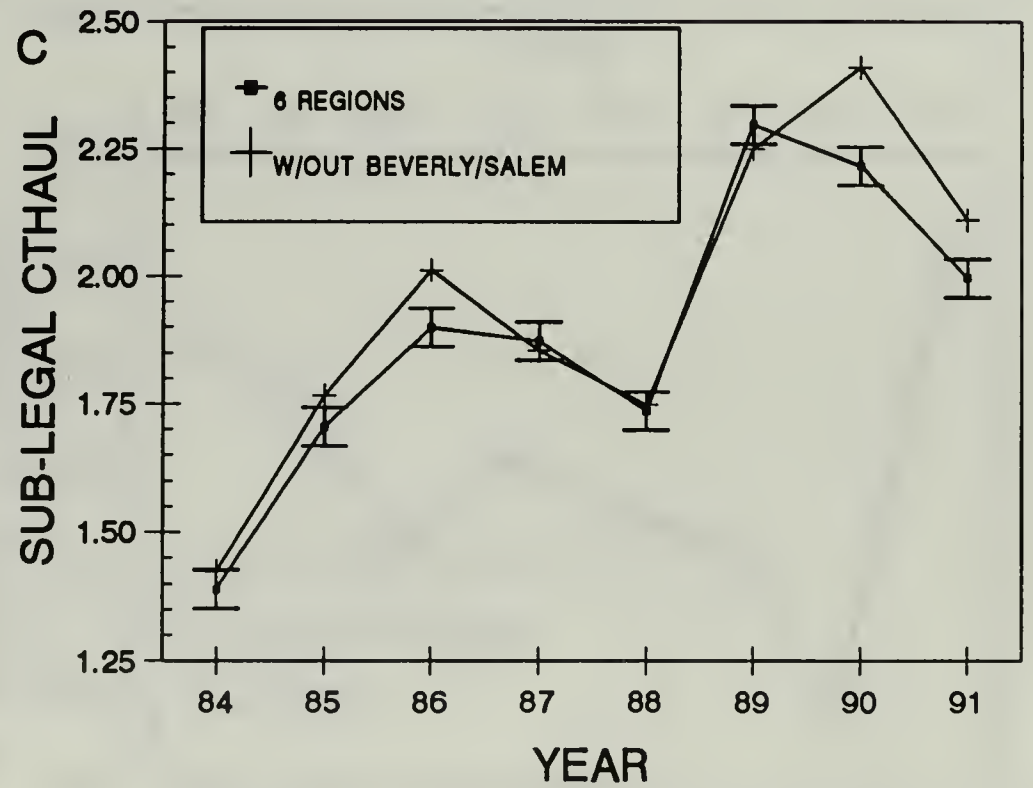


Figure 13(cont.) Estimates of ovigerous catch per trap haul set-over-days (E) ovigerous catch per trap haul (F), mean marketable carapace length (G), and mean ovigerous carapace length (H) using all data and excluding Beverly/Salem data.







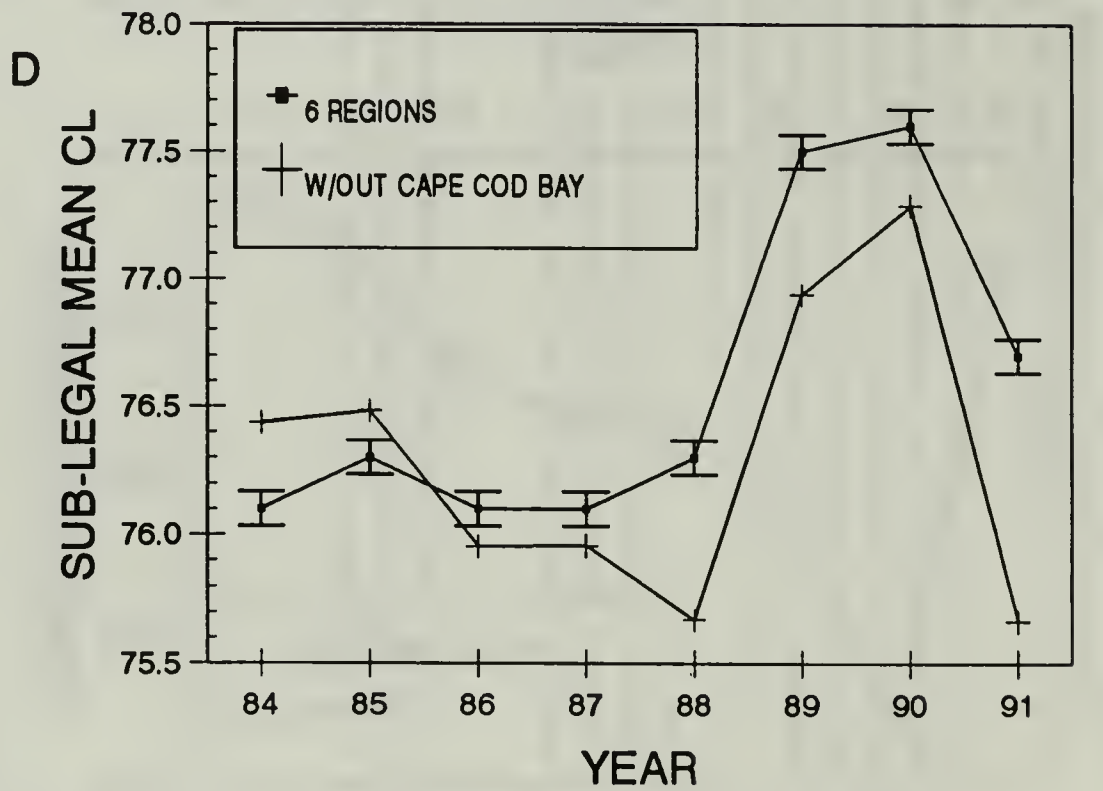


Figure 14. Estimates of standardized catch per trap haul (A), sublegal catch per trap haul set-over-day (B), sublegal catch per trap haul (C), and sublegal mean carapace length (D) using all data and excluding Cape Cod Bay data.

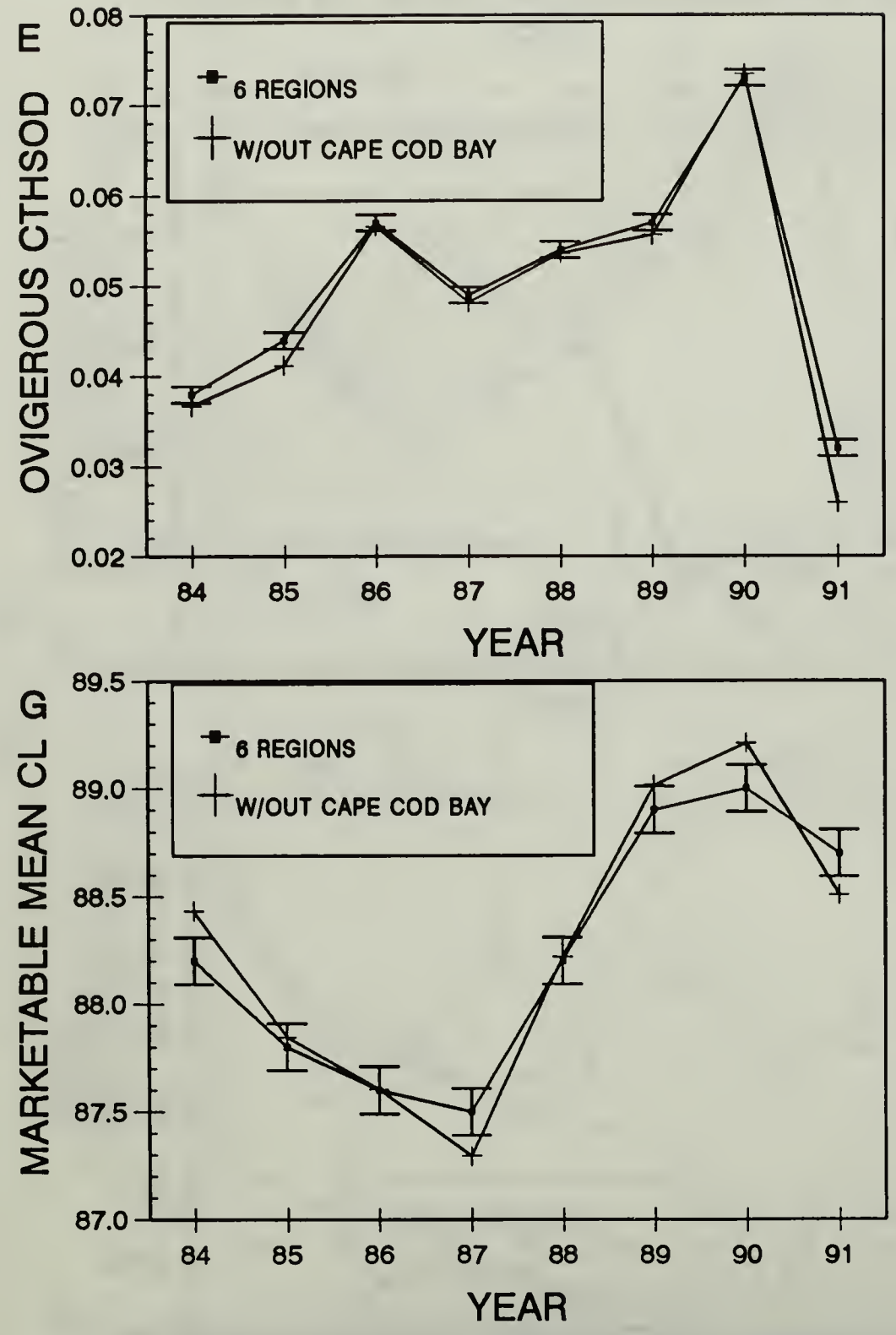


Figure 14(cont.) Estimates of ovigerous catch per trap haul set-over-day (E) ovigerous catch per trap haul (F), mean marketable carapace length (G), and mean ovigerous carapace length (H) using all data and excluding Cape Cod Bay data.

estimates of ovigerous catch rates and size distribution in the outer Cape Cod and Buzzards Bay regions. Such a reduction would decrease required manpower from 196 to 140 man-days. In combination with relative reduction in Cape Cod Bay effort (strategy 1), 120 man-days would be required.

3. Elimination of the Beverly/Salem region. There were significant increases in CTH'_3 estimates with the elimination of the Beverly/Salem region. Other population parameter estimates (e.g. ovigerous and sublegal catch rates and mean carapace length of sublegal lobster) were effected. To continue the 11 year time series generated by the project this option should only be considered as a last resort for situations of severe staff reductions. Elimination of the region would decrease the required man-days from 196 to 168. Combining this strategy with reduction of Cape Cod Bay sampling intensity (strategy 1) and seasonal reductions in sampling frequency (strategy 2) decreases required manpower to 100 man-days.

4. Reducing monthly sampling frequency. Simulations of annual regional estimates produced by one trip per month were highly unstable and should not be considered. Estimates of CTH'_3 for all regions, ovigerous CTHAUL for Buzzards Bay and outer Cape Cod, and mean CL for Cape Ann and outer Cape Cod were strongly affected.

5. Elimination of the Cape Cod Bay region. Many parameter estimates were significantly different when Cape Cod Bay data were eliminated. Magnitude and trends of CTH'_3, sub-legal catch rates, ovigerous catch rates, and mean carapace lengths of marketable, ovigerous and sublegal lobster were severely affected. Sampling should be maintained in this region.

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APPENDIX

Table 1. CTH'3, by state and region, for all marketable lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	0.767	0.785	0.803	0.696	0.825	0.816	0.737	0.820	0.751	0.826	0.795	0.716
Cape Ann	0.732	0.808	0.624	0.663	0.634	0.699	0.669	0.496	0.721	0.904	0.868	0.724
Beverly–Salem	0.934	0.898	0.881	0.835	0.663	0.496	0.611	0.661	0.639	0.827	0.586	0.390
Boston Harbor	—	—	—	1.108	1.254	1.096	1.058	1.057	1.123	1.224	1.160	0.734
Cape Cod Bay	0.710	0.776	0.680	0.479	0.716	0.822	0.533	0.752	0.539	0.630	0.693	0.567
Outer Cape Cod	0.808	0.824	0.765	0.598	0.856	0.811	0.937	0.861	0.923	1.219	1.148	1.339
Buzzards Bay	0.611	0.571	1.110	0.870	0.953	0.907	0.952	1.064	0.934	0.598	0.575	0.817

Table 2. CTHSOD, by state and region, for all sub–legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	0.580	0.672	0.718	0.521	0.647	0.700	0.578	0.509	0.695	0.716	0.665	0.465
Cape Ann	0.067	0.109	0.586	0.450	0.395	0.474	0.417	0.388	0.670	0.589	0.728	0.726
Beverly–Salem	0.708	0.711	1.263	0.948	0.833	0.801	0.863	0.353	0.780	0.408	0.324	0.411
Boston Harbor	—	—	—	0.901	1.162	1.138	1.156	0.639	0.966	1.103	0.924	0.839
Cape Cod Bay	0.710	1.013	0.639	0.322	0.594	0.551	0.371	0.438	0.595	0.727	0.716	0.298
Outer Cape Cod	0.037	0.024	0.038	0.033	0.035	0.027	0.088	0.064	0.066	0.078	0.077	0.088
Buzzards Bay	0.787	0.620	0.638	0.785	0.848	1.312	0.871	1.153	1.188	1.236	1.072	0.784

Table 3. CTHAUL, by state and region, for all sub–legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	1.473	1.401	1.624	1.389	1.705	1.899	1.873	1.736	2.297	2.216	1.996	1.460
Cape Ann	0.256	0.199	1.044	0.909	1.031	1.126	1.143	1.062	1.765	1.782	1.783	1.661
Beverly–Salem	1.855	1.713	2.526	2.504	2.567	2.435	3.482	1.862	3.477	1.867	1.563	1.502
Boston Harbor	—	—	—	2.773	3.038	3.314	3.334	1.959	3.104	3.382	2.451	2.069
Cape Cod Bay	1.544	1.680	1.345	0.825	1.337	1.512	1.031	1.442	1.742	1.921	2.086	1.065
Outer Cape Cod	0.233	0.145	0.210	0.189	0.160	0.161	0.324	0.353	0.306	0.453	0.452	0.490
Buzzards Bay	2.381	1.916	2.316	1.965	2.452	3.118	3.090	3.722	3.984	3.994	3.181	2.602

Table 4. Percent of females ovigerous, by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	5.9	7.7	10.9	9.1	8.6	9.1	9.2	8.8	10.0	10.9	9.8	11.9
Cape Ann	1.7	3.1	4.4	3.2	4.6	5.0	4.5	3.5	6.3	6.9	4.3	6.7
Beverly–Salem	1.7	2.8	1.2	0.4	1.9	1.1	1.8	1.5	1.6	1.8	3.2	3.9
Boston Harbor	—	—	—	1.4	1.2	2.0	1.7	2.0	2.1	2.7	2.8	3.0
Cape Cod Bay	3.9	3.1	3.7	3.1	3.2	2.1	3.9	2.9	3.0	3.3	5.4	6.8
Outer Cape Cod	11.1	23.0	30.3	26.8	22.3	28.9	16.9	21.4	27.4	24.5	18.3	27.7
Buzzards Bay	16.0	16.9	32.5	26.6	25.0	25.3	31.0	27.8	29.2	35.0	28.2	28.8

Table 5. CTHSOD, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	0.024	0.027	0.050	0.038	0.044	0.057	0.049	0.054	0.057	0.073	0.032	0.054
Cape Ann	0.002	0.011	0.024	0.015	0.016	0.017	0.016	0.010	0.037	0.035	0.024	0.050
Beverly–Salem	0.011	0.009	0.008	0.003	0.011	0.004	0.010	0.004	0.009	0.005	0.008	0.014
Boston Harbor	—	—	—	0.009	0.007	0.015	0.012	0.012	0.010	0.028	0.017	0.017
Cape Cod Bay	0.020	0.025	0.016	0.009	0.015	0.010	0.012	0.009	0.014	0.017	0.028	0.016
Outer Cape Cod	0.012	0.028	0.040	0.030	0.038	0.032	0.034	0.030	0.043	0.055	0.038	0.076
Buzzards Bay	0.079	0.053	0.230	0.183	0.193	0.297	0.234	0.289	0.270	0.349	0.073	0.197

Table 6. CTHAUL, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	0.073	0.078	0.179	0.116	0.133	0.167	0.183	0.189	0.211	0.282	0.140	0.227
Cape Ann	0.010	0.016	0.038	0.027	0.039	0.047	0.048	0.031	0.096	0.109	0.056	0.088
Beverly–Salem	0.025	0.033	0.016	0.006	0.033	0.018	0.036	0.021	0.039	0.023	0.049	0.047
Boston Harbor	—	—	—	0.030	0.025	0.050	0.037	0.038	0.043	0.075	0.064	0.046
Cape Cod Bay	0.048	0.048	0.040	0.024	0.040	0.031	0.038	0.034	0.039	0.055	0.091	0.056
Outer Cape Cod	0.081	0.178	0.242	0.170	0.176	0.225	0.157	0.198	0.258	0.342	0.251	0.453
Buzzards Bay	0.243	0.139	0.828	0.515	0.555	0.748	0.889	0.929	0.953	1.291	0.359	0.847

Table 7. Estimated fishing pressure index, by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	86	87	86	86	88	88	89	90	88	87	89	89
Cape Ann	91	92	87	89	87	87	88	90	84	81	90	87
Beverly–Salem	89	92	94	88	96	96	97	98	96	95	97	98
Boston Harbor	—	—	—	93	94	96	96	96	96	95	96	95
Cape Cod Bay	90	93	92	94	93	94	92	94	94	93	91	92
Outer Cape Cod	46	43	42	38	48	46	54	57	47	50	54	57
Buzzards Bay	98	96	96	94	96	97	97	97	95	94	95	97

Table 8A. Total instantaneous (Z)* and total annual (A)** mortality estimates (Gulland, 1969) of American lobster by state and region, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	1.58 *	1.7	1.66	1.66	1.76	1.80	1.90	1.86	1.80	1.76	1.90	1.92
	79% **	82	81%	81%	83%	84%	85%	84%	83%	83%	85%	85%
Cape Ann	1.65	2.18	1.72	1.92	1.94	2.03	1.85	1.75	1.55	1.39	1.97	1.87
	81%	89%	82%	85%	86%	87%	84%	83%	79%	75%	86%	85%
Beverly–Salem	1.97	2.15	2.41	2.71	3.64	3.60	3.49	3.31	3.59	2.81	3.49	3.12
	86%	88%	91%	93%	97%	97%	97%	96%	97%	94%	97%	96%
Boston Harbor	—	—	—	2.52	3.59	2.60	2.77	2.86	2.96	3.00	3.40	3.54
	—	—	—	92%	97%	93%	94%	94%	95%	95%	97%	97%
Cape Cod Bay	2.53	2.69	2.42	2.52	2.31	2.83	2.26	2.74	2.43	2.46	2.33	2.58
	92%	93%	91%	92%	90%	94%	90%	94%	91%	91%	90%	92%
Outer Cape Cod	0.43	0.46	0.42	0.33	0.52	0.51	0.80	0.71	0.62	0.63	0.77	0.78
	35%	37%	34%	28%	41%	40%	55%	51%	46%	47%	54%	54%
Buzzards Bay	3.02	3.00	8.64	3.14	3.55	3.71	3.48	3.18	3.13	2.60	3.50	3.81
	95%	95%	99%	96%	97%	98%	97%	96%	96%	93%	97%	98%

Table 8B. Total instantaneous (Z)* and total annual (A)** mortality estimates (Beverton and Holt, 1956) of American lobster by state and region, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	1.35 *	1.4	1.39	1.41	1.47	1.49	1.54	1.56	1.53	1.50	1.73	1.70
	74% **	77	75%	76%	77%	78%	79%	79%	78%	78%	82%	82%
Cape Ann	1.32	1.39	1.35	1.52	1.33	1.32	1.39	1.51	1.27	1.66	1.77	1.57
	73%	75%	74%	78%	74%	73%	75%	78%	72%	81%	83%	79%
Beverly–Salem	1.59	1.7	1.85	1.78	1.96	1.99	2.16	1.98	2.01	1.83	2.29	2.50
	80%	82%	84%	83%	86%	86%	88%	86%	87%	84%	90%	92%
Boston Harbor	—	—	—	1.82	1.75	1.92	1.88	1.84	1.94	1.87	2.19	2.14
	—	—	—	84%	83%	85%	85%	84%	86%	85%	89%	88%
Cape Cod Bay	1.64	1.92	1.72	2.07	1.88	1.92	1.78	1.87	1.97	1.95	1.96	2.01
	81%	85%	82%	87%	85%	85%	83%	85%	86%	86%	86%	87%
Outer Cape Cod	0.54	0.55	0.53	0.52	0.57	0.55	0.66	0.66	0.62	0.63	0.71	0.72
	42%	42%	41%	41%	43%	42%	48%	48%	46%	47%	51%	51%
Buzzards Bay	2.97	2.53	2.26	2.21	2.36	2.41	2.36	2.35	2.14	2.27	3.08	2.70
	95%	92%	90%	89%	91%	91%	91%	94%	88%	90%	95%	93%

Table 9. Instantaneous fishing mortality estimates (F), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	1.14	1.21	1.17	1.19	1.25	1.28	1.32	1.36	1.36	1.32	1.43	1.44
Cape Ann	1.33	1.47	1.11	1.33	1.28	1.22	1.30	1.37	1.12	1.04	1.50	1.32
Beverly–Salem	1.42	1.47	1.64	1.68	1.81	1.93	1.89	2.02	1.95	1.86	2.08	2.16
Boston Harbor	—	—	—	1.77	1.70	1.80	1.87	1.83	1.94	1.86	2.01	1.97
Cape Cod Bay	1.53	1.60	1.58	1.73	1.59	1.70	1.56	1.70	1.82	1.72	1.66	1.71
Outer Cape Cod	0.47	0.48	0.45	0.42	0.47	0.47	0.57	0.53	0.54	0.51	0.59	0.61
Buzzards Bay	2.32	2.13	1.94	1.80	2.04	2.11	2.08	2.06	1.95	1.97	2.34	2.26

Table 10. Estimated exploitation rate (μ), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	0.62	0.64	0.63	0.64	0.65	0.66	0.68	0.69	0.69	0.69	0.68	0.69
Cape Ann	0.74	0.80	0.61	0.68	0.71	0.67	0.70	0.71	0.63	0.51	0.70	0.67
Beverly–Salem	0.71	0.71	0.75	0.79	0.79	0.83	0.77	0.88	0.76	0.85	0.82	0.79
Boston Harbor	—	—	—	0.82	0.81	0.80	0.84	0.84	0.86	0.85	0.82	0.81
Cape Cod Bay	0.75	0.71	0.75	0.73	0.72	0.75	0.73	0.77	0.79	0.76	0.73	0.74
Outer Cape Cod	0.37	0.37	0.35	0.33	0.36	0.36	0.41	0.38	0.40	0.38	0.42	0.44
Buzzards Bay	0.74	0.78	0.77	0.72	0.79	0.80	0.80	0.82	0.80	0.78	0.72	0.78

Table 11. Mean carapace length (mm), by state and region, for all marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	88.5	87.9	88.1	88.2	87.8	87.6	87.5	88.2	88.9	89.0	88.7	88.8
Cape Ann	88.6	88.3	88.3	87.9	88.4	88.3	88.0	88.3	89.3	90.3	88.4	88.8
Beverly–Salem	87.6	87.0	86.6	86.9	86.2	86.2	85.8	87.1	87.7	88.3	87.5	87.2
Boston Harbor	—	—	—	86.8	86.9	86.4	86.6	87.5	88.0	88.1	87.8	87.9
Cape Cod Bay	87.2	86.4	86.9	86.1	86.4	86.3	86.7	87.3	87.7	87.7	88.1	88.2
Outer Cape Cod	98.2	97.5	97.4	99.7	97.0	96.3	94.6	95.2	96.5	96.1	95.3	95.2
Buzzards Bay	84.7	85.2	85.7	85.8	85.2	85.3	85.3	86.1	87.4	87.0	86.4	86.9

Table 12. Mean carapace length (mm), by state and region for all sub–legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	75.8	76.3	76.2	76.1	76.3	76.1	76.1	76.3	77.5	77.6	76.7	76.2
Cape Ann	78.0	77.7	77.5	77.3	77.6	77.1	75.9	77.0	78.3	78.8	78.7	77.9
Beverly–Salem	74.3	76.5	74.9	76.1	75.9	74.7	74.7	74.5	76.4	76.1	73.4	73.5
Boston Harbor	—	—	—	77.1	76.9	76.9	76.5	75.6	76.8	77.4	75.4	74.6
Cape Cod Bay	76.6	76.4	76.7	75.6	76.1	76.2	75.6	76.9	77.9	77.8	77.4	76.8
Outer Cape Cod	75.9	76.2	77.1	75.1	76.6	75.9	77.0	77.1	76.8	78.8	78.8	79.0
Buzzards Bay	75.8	75.5	76.8	76.4	76.1	76.0	76.6	76.3	77.7	77.4	76.6	77.1

Table 13. Mean carapace length (mm) of all ovigerous female American lobster, by state and region, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	88.5	87.6	88.6	87.4	87.9	88.1	87.1	87.2	88.5	88.0	86.0	85.5
Cape Ann	109.0	100.3	94.3	90.5	93.8	95.0	91.6	94.0	100.4	95.1	91.7	91.9
Beverly–Salem	80.5	84.5	85.8	83.5	85.9	83.5	81.8	83.0	85.2	85.5	83.8	81.6
Boston Harbor	—	—	—	82.1	84.0	81.3	82.3	83.7	83.0	83.8	82.0	82.0
Cape Cod Bay	86.4	83.8	85.5	84.4	85.2	86.8	87.0	84.7	86.1	85.0	83.9	84.1
Outer Cape Cod	109.8	106.1	108.0	107.1	106.9	107.3	102.5	105.2	105.4	104.6	101.9	99.2
Buzzards Bay	78.1	79.6	81.6	83.0	80.1	79.4	80.2	80.6	81.3	80.8	79.8	79.9

Table 14. Cull rate (percent), by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	10.0	10.8	10.7	14.8	18.1	20.9	17.0	18.2	19.2	18.6	18.1	18.5
Cape Ann	10.0	9.8	10.5	11.5	23.9	25.3	20.2	21.2	16.7	16.7	19.7	18.2
Beverly–Salem	8.3	8.6	10.2	20.9	23.0	30.0	24.1	26.3	28.6	27.3	28.9	22.7
Boston Harbor	—	—	—	13.3	19.3	19.1	16.9	16.3	13.8	14.7	13.5	17.2
Cape Cod Bay	11.1	10.7	10.9	15.6	18.3	21.6	16.2	17.4	22.8	20.5	18.9	18.3
Outer Cape Cod	5.7	11.3	8.9	13.0	13.4	16.1	12.6	15.0	14.0	15.5	13.2	15.7
Buzzards Bay	13.5	14.7	12.4	12.4	13.4	14.6	15.1	15.6	12.6	13.6	13.9	19.3

Table 15. Cull rate (percent), by state and region, for all legal–sized American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	8.1	9.7	9.2	12.7	14.8	17.0	14.7	15.7	14.9	15.4	15.6	17.1
Cape Ann	10.7	9.6	7.5	10.4	19.4	20.3	18.0	19.3	13.9	13.7	16.8	18.3
Beverly–Salem	4.3	7.7	7.4	15.5	19.3	22.1	17.1	21.4	18.7	25.6	22.8	19.9
Boston Harbor	—	—	—	10.1	16.2	15.8	12.9	13.1	9.9	9.9	12.3	14.0
Cape Cod Bay	9.3	9.3	10.0	13.2	14.5	18.1	15.0	15.6	12.0	16.3	17.8	16.8
Outer Cape Cod	5.3	10.3	8.1	13.3	12.5	14.9	13.1	14.3	13.3	14.1	12.8	15.3
Buzzards Bay	16.1	13.2	12.7	12.3	13.8	13.6	15.2	14.1	12.6	12.6	11.5	22.2

Table 16. Cull rate (percent), by state and region, for marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	8.2	9.9	9.2	13.2	16.2	17.6	14.7	16.0	15.2	15.6	16.1	17.6
Cape Ann	10.8	9.8	7.3	10.5	20.9	20.7	18.4	19.9	14.0	14.2	16.8	18.1
Beverly–Salem	4.4	8.0	7.4	15.6	18.5	22.2	17.2	21.3	18.9	23.8	23.1	20.0
Boston Harbor	—	—	—	10.2	16.2	15.7	12.8	13.1	9.9	9.9	12.4	14.0
Cape Cod Bay	9.3	9.3	10.0	13.2	15.9	18.2	14.8	15.6	19.1	16.2	17.8	16.7
Outer Cape Cod	5.3	10.9	8.6	14.8	12.9	16.8	13.2	14.9	13.9	14.6	14.1	16.8
Buzzards Bay	16.9	13.1	12.3	12.6	15.4	14.1	15.4	14.7	13.0	12.4	11.7	22.5

Table 17. Cull rate (percent), by state and region, for sub–legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	11.2	11.5	11.6	16.1	20.2	23.2	18.2	19.6	21.1	20.2	19.2	19.3
Cape Ann	8.0	10.6	12.6	12.2	26.9	28.7	21.5	22.1	17.9	18.3	21.0	18.2
Beverly–Salem	10.0	9.0	11.2	22.3	24.0	31.8	25.3	28.6	30.8	29.2	31.6	23.5
Boston Harbor	—	—	—	14.5	20.5	20.0	18.0	18.0	15.2	16.4	13.9	18.3
Cape Cod Bay	11.9	11.3	11.4	17.0	20.2	23.4	16.8	18.3	24.0	21.8	19.2	19.0
Outer Cape Cod	7.8	17.9	13.5	11.7	18.6	22.8	11.0	16.9	17.1	20.7	14.3	17.1
Buzzards Bay	12.7	15.2	12.2	12.4	13.3	14.9	15.0	16.2	12.6	13.9	14.5	18.3

Table 18. Percent trap mortality by state and region for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1992.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
State	0.15	0.04	0.22	0.15	0.18	0.20	0.10	0.15	0.12	0.17	0.37	0.08
Cape Ann	0.00	0.00	0.09	0.27	0.03	0.16	0.00	0.03	0.13	0.09	0.48	0.10
Beverly–Salem	0.00	0.00	0.00	0.00	0.04	0.22	0.03	0.19	0.14	0.29	0.41	0.13
Boston Harbor	—	—	—	0.00	0.03	0.03	0.23	0.09	0.03	0.04	0.01	0.03
Cape Cod Bay	0.00	0.02	0.03	0.00	0.00	0.02	0.15	0.00	0.02	0.05	0.02	0.02
Outer Cape Cod	0.46	0.22	0.23	0.48	0.40	0.85	0.27	0.66	0.47	0.62	0.35	0.24
Buzzards Bay	0.62	0.00	1.13	0.43	0.76	0.25	0.01	0.18	0.11	0.18	1.74	0.10